MAY 1985 VOL. 7 NO. 5

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X-Y Positioning

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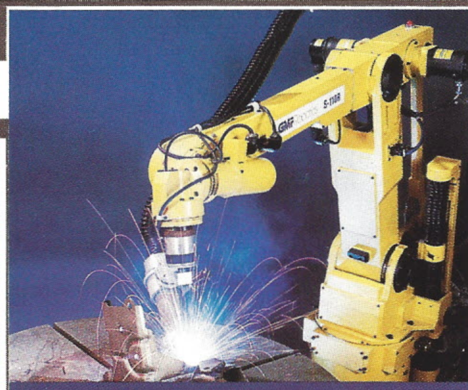

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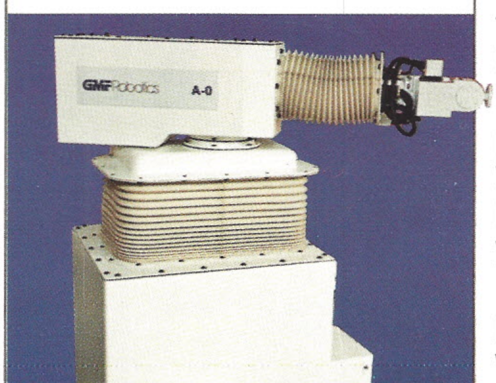

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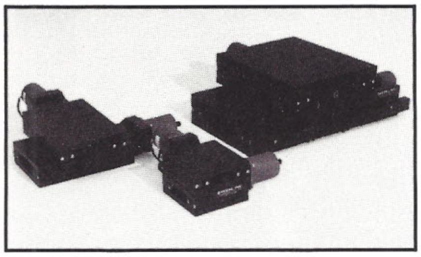
Circle 11

Product News

Motion Control

X-Y Positioning Tables



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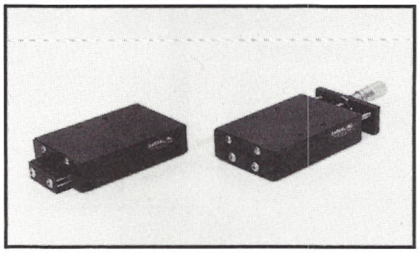

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Circle 27

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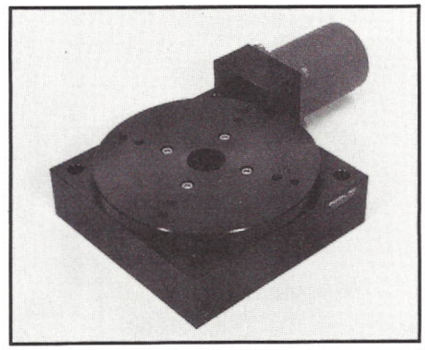

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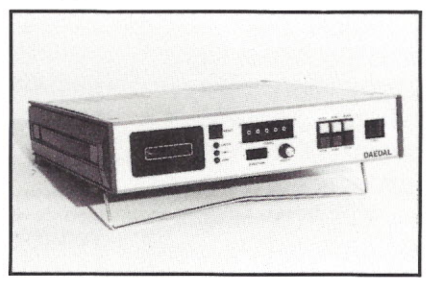

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Circle 29

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Business Publications Audit

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ROBOTICS AGE—(ISSN 0197-1905) is published monthly by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, NH 03458, phone (603) 924-7136. Address subscriptions, changes of address, USPC Form 3579, and fulfillment questions to *Robotics Age* Subscriptions, 174 Concord Street, Peterborough, NH 03458. Second class postage paid at Peterborough, NH and at additional mailing offices. **POSTMASTER:** Send address changes to ROBOTICS AGE, 174 Concord St., Peterborough, NH 03458.

Subscriptions are $24 for one year (12 issues), $45 for two years (24 issues), $63 for three years (36 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are $28 for one year, $53 for two years, $75 for three years. For other countries, subscriptions are $32 for one year, surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is $3 in the U.S., $3.50 in Canada and Mexico, $4 in Europe, and $4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

Address all editorial correspondence to the Editor at *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, NH 03458. Opinions expressed by the authors of articles are not necessarily those of *Robotics Age*. To aid in preparation of acceptable articles, an Authors' Guide is available upon request, if accompanied by a self-addressed 8½ by 11 inch envelope with first class postage for 3 ounces. Unacceptable manuscripts will be returned if accompanied by a self-addressed envelope with sufficient first class postage. Not responsible for lost manuscripts or photos.

ROBOTICS AGE™

THE JOURNAL OF INTELLIGENT MACHINES

MAY 1985 VOL. 7 NO. 5

EDITORIAL

FEATURES

DEPARTMENTS

About the cover: This month's cover, supplied by the National Bureau of Standards, pictures a turning center work cell featuring a robot, turning center, and materials buffer table in the Automated Manufacturing Research Facility of NBS. The robot is a Bendix AA gantry and the turning center is a Hardinge Brothers Superslant™ CNC.

Editorial

Existence Proof...

BY CARL HELMERS

The critic has it easy. The easiest thing in the world to do is to be negative. In contrast, it is difficult to create a positive new idea, process, technology, or business. As soon as this is done, critics move in and pick at the results. Sometimes the critics move in as soon as the idea is even suggested. Now, criticism is a healthy part of any technological progress. It provides the "what ifs" necessary to engineer a new concept. Every positive advance in technology has healthy criticism at its inception.

Critical awareness of engineering tradeoffs is one issue. But there is always the difficulty of convincing untutored, even hostile, critics that a new idea will work. Some people cannot see an incremental improvement even when it is presented to them on a silver platter. There are always those who say "it can't be done" upon hearing of a proposed new technological feat. This unhealthy form of criticism is more than just the formal "devil's advocate" position of engineering's creative process. For such critics, the act of being critical takes on a life independent of any valid basis for criticism.

Whatever *it* is, there will be people who criticize with varying degrees of merit. If *it* is some pseudoscientific concept of levitation sans technology and in violation of physical principles, then the critics will tend to be engineers and scientists. They have on their side the weight of extensive knowledge of the physical world. However, if *it* is an engineering use of magnetic repulsion to lower mechanical friction, then no physicist or engineer can base an objection on what is known about the physical world. There may be technical tradeoffs to be made in achieving stable magnetic levitation. The engineers are not violating any physical principles by using them in a vehicle or materials transport system.

The technical and nontechnical critics' polemics against manned aircraft and manned spaceflight are legendary. Almost as strenuous are contemporary objections to the proposed ballistic missile *defense* system. Defusing the critics requires only an existence proof. It is hard to criticize a technology that works. Much of the wind was knocked out of the Strategic Defense Initiative's critics last summer with a simple existence proof: A demonstration was made of a kinetic energy interception and destruction of a dummy Minuteman warhead high over the Pacific Ocean. The interceptor was an aerospace robot, self-guided by an infrared homing sensor to a direct hit on the reentering dummy warhead. Who says "Star Wars" defense systems will not work?

Our cover depicts another example of the existence proof concept in the classical sense of a research program with definite goals. It is a research program crucial to increasing manufacturing productivity in the next decade. Pictured are the contents of one small corner of the National Bureau of Standards Automated Manufacturing Research Facility in Gaithersburg, Maryland. The AMRF's purpose is research and development—exploring the limits of technology in automated manufacturing. Similar to, but broader than, the research programs of individual companies, the AMRF intends to provide a working existence proof of the concept of an automated factory.

The National Bureau of Standards puts particular emphasis on one of the most fundamental questions: How will our manufacturing industries make the transition to automated manufacturing? A proposed answer is inherent in the design of the facility. Whether the concept proves to be the "right" answer is less important than the exploration of the problems involved. The idea of integrated manufacturing requires standards of data communication, data representation, and control structures that can unify the actions of multiple intelligent machines. In the integrated manufacturing facility of the future, each work cell and work center must be coordinated with its neighbors and the overall management of the system. By proposing and experimenting with such standards—in cooperation with the equipment manufacturers—the AMRF's theme is to lay the groundwork for an evolutionary transition via incremental improvements. At each stage of the transition, new equipment and new methods are installed that have real payoffs easily evaluated in isolation. The key to the evolutionary approach is to create a design philosophy for new equipment consistent with future growth toward more integrated automation.

The researchers at the AMRF expect to complete the facility in 1986. Upon completion it will be able to demonstrate automated manufacturing from stock materials and computer-aided design through the machined, finished product. The demonstration will represent an engineering existence proof that a major part of the automated manufacturing goal can be achieved. It will take its place as an advanced existence proof of concept alongside the privately funded research, development, and application efforts of every large manufacturing company. As a publicly funded research project, most if not all of the technology will be available in some form just for the asking. Even if none of the information proves useful in detail, the mere fact of the demonstration facility—its nature as an existence proof—can serve as an inspiration for further practical advances. ■

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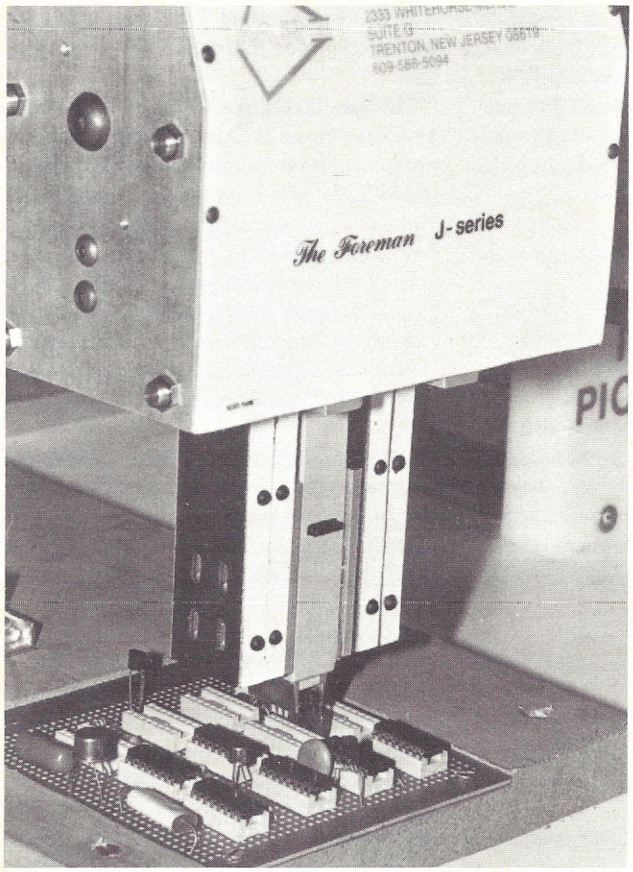

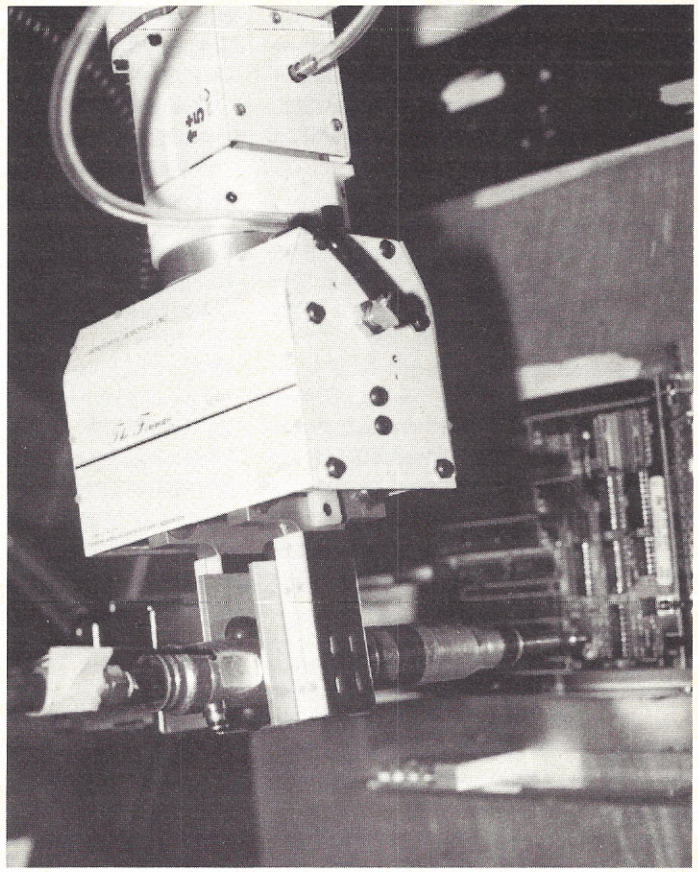

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ROBOTIC INDUSTRIES ria MEMBER ASSOCIATION

Calendar

MAY

1–2 May. Artificial Intelligence and Advanced Computer Technology Conference/Exhibition. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Company, 331 West Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

The direction of AI 85 is commercial, and technical sessions will include such topics as AI in office automation, natural language interfaces, AI in defense systems, computer vision, and the legal and social implications of artificial intelligence.

6–7 May. Applying Robotics Technology in the Textile Industry. Norcross, GA. Contact: Diane Korona, Robotics International, SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 392.

Among textile industry applications to be covered are bale handling; testing; doffing; material, bobbin, and fiber handling; inspection/segregation; creel loading/unloading; carrier loading/unloading, and case packing. The vice-president and the manager of Robot Systems, Inc. will conduct the workshop, which will be worth 12 professional credits toward SME recertification.

6–9 May. 1985 International Tool & Manufacturing Engineering Conference and Exposition. Cobo Hall, Detroit, MI. Contact: Public Relations Dept., Society of Manufacturing Engineers, One SME Dr., Dearborn, MI 48121, telephone (313) 271-0777.

This conference will feature 18 all-day workshops, 17 half-day technical sessions, and a half-day tutorial. Among topics to be addressed are group technology and CIM, artificial intelligence in manufacturing, and computer-aided design and analysis. The concurrent exposition will feature demonstrations of advanced metalworking technologies and equipment in over 100 categories.

7–9 May. Controlling Manufacturing Productivity Through DNC. Airport Hilton Inn, Romulus (Detroit), MI. Contact: Sharilyn Shampine, Program Administrator, Computer and Automated Systems Association, SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (393) 271-1500, ext. 386.

The seminar will emphasize a broad view of digital numerical control by showing the role it plays in bringing factory automation on line in a timely manner. Topics will include network systems, DNC and factory data collection, justification of DNC, and organizational impact of DNC.

8 May. Simple Solutions to Complex Robot Applications. Montclair State College, Upper Montclair, NJ. Contact: Prof. Gideon Nettler, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4294.

This talk, conducted by Michael T. McCraley, Panasonic Industrial Co., is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

8–9 May. Applying Robotics Technology in the Woodworking Industry. Norcross, GA. Contact: Diana Korona, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 392.

This course, worth 12 professional credits toward the SME recertification program, will include topics such as spray painting, surface preparation, palletizing, applying adhesives, material handling, staining, machine loading, packaging, and tool handling. There will also be a display of end-of-arm tooling and sensors and vision systems.

14–16 May. 1985 Test & Measurement World Expo. San Jose Convention Center, San Jose, CA. Contact: Meg Bowen, Conference Director, Test & Measurement World Expo, 215 Brighton Ave., Boston, MA 02134, telephone (617) 254-1445.

The 24 conference sessions will feature more than 100 technical papers on topics such as testing of surface-mounted devices, electro-optics test/optical metrology, process monitoring, the ergonomics and psychology of factory automation, machine vision, and communications and microwave testing. There will also be product demonstrations and a large exhibit.

15–21 May. JAPANMEC '85. Osaka, Japan. Contact: Michael Solomon, Michael Solomon Associates, 509 Madison Ave., Suite 1708, New York, NY 10022, telephone (212) 223-3340.

The Japan International Measuring and Control and Industry Show '85 will be one of the opening events at the the New Osaka International Fairgrounds. Twelve categories of instruments will be on display: precision measuring, metering, optical measuring, electric/electronic measuring, testing, analytical, control, information-transmission, peripheral devices/auxiliary equipment, and other related equipment. Concurrent and at the same location will be FACTRO '85, a new international show devoted to flexible manufacturing systems.

16 May. Design for Manufacturability. Contact: IEEE Continuing Education Dept., IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854, telephone (201) 981-0060, ext. 329 or 330.

This videoconference will be broadcast from 11 a.m. to 4 p.m. EST via satellite through an interactive network (one-way video, two-way audio) to sites in the United States, Canada, and Mexico. Topics will include design guidelines for minimum assembly effort, evaluating a design against a minimum number of parts, design considerations of parts for automatic handling and feeding, design factors to facilitate assembly by automated equipment, and economic considerations of automated manufacturing.

19–23 May. 1985 Annual International Industrial Engineering Conference and Show. Westin Bonaventure Hotel, Los Angeles, CA. Contact: Conference Dept., IIE, 25 Technology Park/Atlanta, Norcross, GA 30092, telephone (404) 449-0460.

Among the large selection of course offerings will be Artificial Intelligence in Manufacturing and System Approach to Manufacturing. The AI seminar will examine the applications of AI techniques to manufacturing and will present major areas of research development emphasis, along with potential payoffs. The system session will cover several CAM-related systems/physical simulators, including a CNC system, automated model warehouse, automatic quality control system, computerized drilling machine, and assembly robot.

20–22 May. Commercial Artificial Intelligence: Myths & Realities. Century Plaza Hotel, Los Angeles, CA. Contact: Lynn M. Bentley, Marketing Manager, Gartner Group, Inc., 72 Cummings Point Rd., PO Box 10212, Stamford, CT 06904, telephone (203) 964-0096.

The emphasis of this conference will be real-world applications of artificial intelligence in large corporations and the structure of the emerging AI industry. Topics to be covered include AI in computer operations, manufacturing, financial services, and office information systems; AI-based user interfaces; and AI and personal computers. *Continued on page 19*

THE ABCs OF X-Y POSITIONING

Richard M. Dougans
Chief Engineer
Design Components, Inc.
Franklin, MA 02038

X–Y positioning tables have been integral parts of machine tools for 75 years. Still, many engineers and designers are unfamiliar with the latest generation of positioning tables, which bears little resemblance to the comparatively massive tables found on large lathes, milling machines, and other production equipment.

These new, highly accurate tables use precision antifriction bearings—instead of massive metal-to-metal sliding contact ways—and provide a low-cost, easy to implement means of transfer and positioning. They permit linear and, in a few special cases, rotary motion with very low friction; motion is accurate, repeatable, and routinely controlled by open-loop or closed-loop electronics.

An X–Y positioning table can be incorporated into an OEM-built machine, or it can be one of several subsystems assembled into a production system. Let's take a look at a few of the applications for X–Y positioning tables.

ELECTRONICS MANUFACTURING

Perhaps the largest user of small positioning tables is the electronics industry, due to its large volume of small, precise components. In the manufacturing of integrated circuits, positioning tables are used for scribing, dicing, and slicing substrate material. In these applications, the positioning table moves a laser beam or a mechanical cutting tool across the wafer in controlled patterns—or vice versa.

Quite often, after integrated circuits are cut and packaged, other positioning tables are used for micropositioning in hybrid circuit manufacturing and quality control. In these kinds of manufacturing operations, the positioning table moves the circuits in small increments, allowing examination under a microscope. The accurate and repeatable movement of the X–Y positioning table, coupled with its low friction, makes possible assembly and quality-control operations that would have been impossible just a decade ago.

Other areas of electronics manufacturing use positioning tables in automated insertion operations. For example, several companies are now offering terminal insertion machinery that will insert hundreds of terminals in printed circuit boards in a fraction of the time required with conventional manual or semiautomatic methods. Photo 1 shows a typical example of such a system. Application of positioning tables in automated component insertion con-

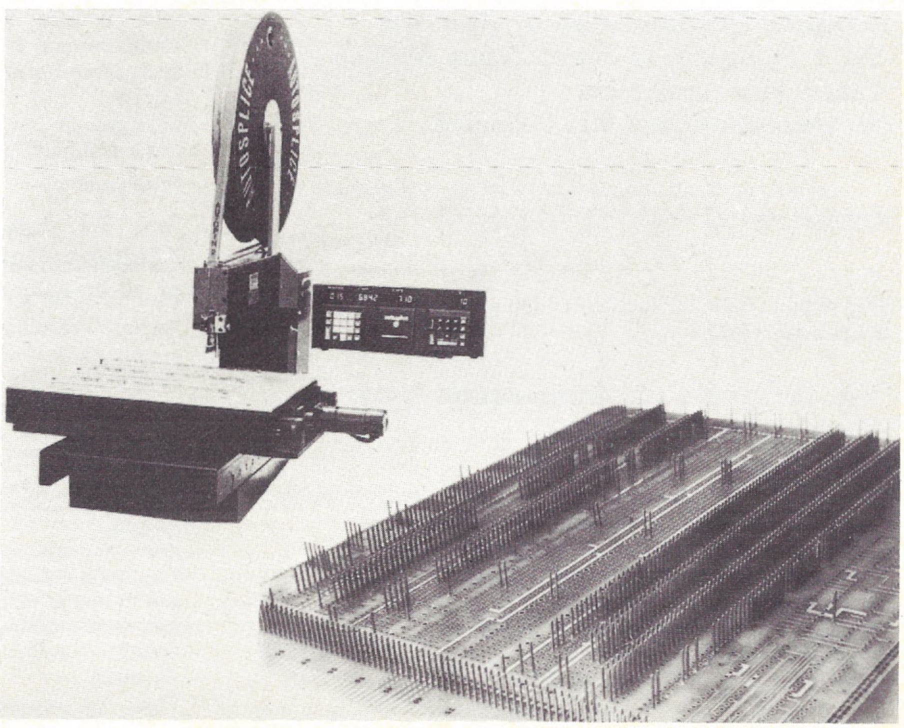

Photo 1. Many industrial, commercial, and laboratory automation applications require the use of X–Y positioning systems. Here we see an electronics packaging application in which an X–Y positioning sub-assembly positions a board for insertion of wirewrap pins. This Autosplice Computer Numerical Control Insertion System inserts up to 3000 terminal pins per hour.

tinues to grow at an increasing rate. This growth is being accelerated by the availability of inexpensive, computer-controlled automation equipment.

MATERIAL HANDLING

In addition to the electronics manufacturing marketplace, X–Y positioning tables are also making inroads in material handling and assembly. An entirely new robotics market is developing around numerically controlled handling equipment coupled to fast and low-mass positioning tables.

For example, a typical application is inserting hundreds of small pharmaceutical vials in the small compartments of shipping containers. Eliminated are tedious manual operations that characteristically have omissions and frequent breakage due to human error.

Likewise, positioning tables are ideally suited for light drilling and tapping positioning in machine-tool applications. They are never substitutes for the heavy-duty tables found on large machine tools; instead, they provide a way to quickly position parts for light machining.

The above examples just scratch the surface of applications for X–Y positioning tables. There are numerous other applications in metrology, optics, instrumentation, and medical applications, among others.

DIFFERENT TYPES AVAILABLE

With new applications for X–Y positioning tables being discovered almost daily, it is instructive to discuss the types of tables that are available. The principal difference that sets table styles apart is generally the bearing technology incorporated.

Ball-bushing or recirculating linear bearings. The ball-bushing, perhaps the most common linear bearing, is the basis for many X–Y positioning tables. A positioning table configured in this manner consists of two sets of ball-bushings riding on two polished and ground shafts.

Because the ball-bushings can travel along a shaft of any practical length—up to many feet if required—this approach to X–Y positioning is unusually flexible in regard to physical size.

On the debit side, the design flexibility of the ball-bushing approach turns out to be a weakness. The ball-bushing style of X–Y positioning table requires much hand work by skilled people. Custom designs are easily conceived and executed on a one-by-one basis, but the hand work is prohibitively expensive if a number of copies of the same design must be manufactured.

Nonrecirculating bearing type. In contrast to the ball-bearing type of linear bearing, this constrained bearing approach does not use a system of recirculating balls. Instead, the balls are held in a retainer and roll against precision shafts or V-ways mounted to the stationary surface of the table. The moving surface of the table forms the outer "race" of the bearing. Several variations using roller or ball elements are currently available.

The advantages of the nonrecirculating linear bearing are many. From a design point of view, they offer somewhat less friction and a simpler basic mechanism than those based on recirculating antifriction elements. But in a more general sense, the constrained bearing positioning table eliminates the headache of custom design, fabrication, and testing the linear positioning system.

Chassis-slide. Another approach to X–Y positioning is based on the use of inexpensive chassis-slide type mechanisms. These are essentially light-duty linear bearings, usually constructed from sheet metal. They are often used in electronic chassis or as hand-driven microfilm readers, where loose tolerances are acceptable and can be corrected by the eye of the operator. The strong point of such mechanisms is their low price and satisfactory performance where high precision and repeatability are not required. They should *not* be considered for high-duty cycle, motor-powered applications, or those involving even moderate loads or shock.

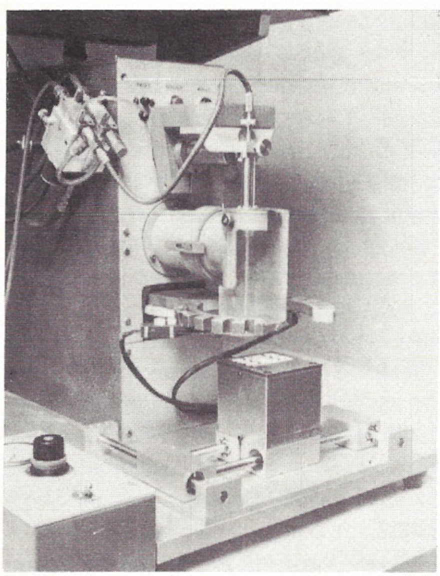

Photo 2. In their MAT-800 Airbrasive Trimming systems, S.S. White employs three modified ball slides as a hybrid X–Y positioner to provide X–Y, plus Z position accuracy and repeatability while keeping costs low. Off-the-shelf slides combine to ensure trimming probe contact and to provide a right angle drive of stage and a speed trimming cycle.

The increasing trend among manufacturers is to purchase a complete subassembly for incorporation into a larger assembly. Under these conditions, it might be unwise to get involved with "build-it-yourself" projects, especially if several machines are required. In essence, the manufacturer is buying a guaranteed performance specification when he buys a preassembled positioning table.

Of the various types available, those using balls rather than rollers offer the advantage of self-cleaning—pushing foreign matter out of the way, rather than having to run over or crush it. This makes them less susceptible to such bearing destroyers as silica and alumina dust and other contaminants typically found in electronics and industrial manufacturing. Accuracy and repeatability are typically very high in these types of positioning tables. Tolerances of 0.0001 inch/inch travel are typical.

Positioning tables based on roller elements offer higher load ratings than ball units. Much like a conventional roller bearing, the rollers in the linear bearing offer line contact, rather than point contact, thus increasing their load rating. On the debit side, roller-based linear bearings tend to require extremely precise assembly and positive protection from contamination.

WHAT SPECIFICATIONS ARE IMPORTANT?

With the different types of X–Y tables thus placed in perspective, it is useful to list the key specifications that should be determined before purchasing a particular type. Let's take a look at these, one by one.

Accuracy. This specification refers to the table's ability to travel in a straight line relative to some known reference plane. Accuracy is usually specified as deviation from perfect straight line travel, in inches per inch of travel.

The constrained nonrecirculating type of linear bearing offers the highest ac-

curacy, measuring down to 0.0001 inch/inch travel or better. The recirculating ball-bushing type also offers high accuracy, but final system performance depends largely on very careful selection, installation, and testing of the individual components. The chassis-slide type of bearing, basically a nonprecision type of mechanism, offers accuracy in the 0.01 inch/inch travel range.

Repeatability. This specification refers to the positioning table's ability to return to the same position or series of positions under repeated cycling. Constrained type bearings can offer a repeatability of less than 0.0001 inch typically. Once again, the repeatability of recirculating ball-bushing bearings depends largely on precise assembly and installation.

Lifetime. This specification refers to the cumulative number of linear inches of travel guaranteed by the manufacturer of the positioning table. Lifetime is correlated to load rating. If the positioning table is applied properly, its lifetime as a component normally exceeds that of the machine in which it is placed, due to such factors as lower reliability linkages and rotating and/or reciprocating equipment.

Load Rating. This specification refers to the maximum permissible load of the positioning table, expressed in pounds. Load rating is usually not a major constraint on small format table designs for non-machine-tool applications.

Friction. In general, friction is a direct function of linear bearing preload. Nonrecirculating bearings offer the lowest friction, especially if designed with balls. Roller-based, nonrecirculating bearings offer somewhat higher friction because of their line contact. Ball-bushings have low-friction characteristics but are very sensitive to preload adjustment and alignment.

Mass. This characteristic should be considered in servodesign, especially in high-speed applications. Modern designs based on lightweight, nonferrous alloys minimize inertia; however, for maximum dimensional stability, heavier castings are used.

CHOICE OF DRIVE OPTIONS

After selecting a positioning table, the manufacturer will have to consider the drive options. Positioning tables can be indexed using either open-loop or closed-loop control systems. Let's take a look at these two different philosophies.

Open-loop control uses stepping motors to position the table. Stepping motors respond to pulse commands from a controller. The term "open-loop" refers to the absence of a feedback sensor to tell the controller the exact position of the table. Instead, the stepping motor moves in small angular increments, each increment being a response to a pulse command from the controller. Commonly, the stepping motor turns 1.8 degrees with every pulse; 200 pulses will move the motor a total of 360 degrees. By coupling the motor to the positioning table with a lead screw, the linear position of the table becomes a direct function of the angular position of the stepping motor.

For many applications, open-loop control is easy to implement, relatively inexpensive, and inherently digital. Controllers tend to be simple electronic interfaces. Open-loop control has the added advantage of adapting well to microcomputer control. Computers work with a series of on/off commands, and these commands can be converted into position commands for the stepping motor with very little additional electronics.

Although open-loop control is simple, it suffers from a performance disadvantage. At linear speeds beyond about 10 inches/second, open-loop approaches are not as feasible. The stepping motor's lower torque at high pulse rates can cause the motor to "miss" pulse commands. If the stepping motor misses a command, there is no way for it or the controller to know that this has occurred. Thus, errors can be introduced into positioning accuracy—and there is no simple way to make corrections.

A closed-loop control system is based on the use of a servomotor and a position sensor. Servomotors can be used to move the lead screws on an X–Y positioning table and offer precise, powerful, and high-speed movement. The position sensor can also eliminate tolerance errors and backlash. High-performance positioning systems, as well as large, massive tables generally require the use of a closed-loop system.

This performance advantage comes at a price. System control electronics are more complicated and expensive. The final choice between the two types of controls depends largely on the performance requirements needed.

SHOULD YOU MAKE OR BUY?

One of the biggest decisions facing the user of a positioning system is whether to buy a complete positioning machine from an OEM manufacturer or build a custom machine using in-house capability. In other words, how does a user resolve the make or buy decision?

The first question to answer is a simple one: Is an in-house capability available? Designing a positioning system is not difficult, but it does require competent engineering and follow-up. Often, manufacturers have in-house design engineering departments whose expertise can be applied to building a positioning system. Manufacturers of positioning tables and control systems can also help by supplying in-plant engineering departments with design assistance.

The question of proprietary information also enters the picture. The application of the positioning system may involve sensitive or classified manufacturing processes, and the manufacturer may not wish outside suppliers to be involved. Further, new or proprietary processes may not appear profitable enough to an equipment supplier. In such cases, the manufacturer will have no choice except to build a positioning system in house.

The time factor may suggest buying from an outside source rather than spending several months designing and debugging an in-house system, particularly for a one-time application. If many machines are required, it may tax the in-house capabilities of a user, and it may make more sense to buy from an outside supplier.

Whatever decision is reached, the end user should be well informed about the various approaches to X–Y positioning. The goal is to refrain from buying more sophistication than needed, while still obtaining a positioning system that meets all requirements and specifications.

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A COMPLIANT MECHANICAL GRIPPER

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A problem with most existing mechanical hands or grippers used as robotic end effectors is lack of compliance. Usually, the individual fingers are composed of rigid sections that can be mechanically damaged or can cause mechanical damage on impact with other objects. The reason pneumatic end effectors are so popular in commercial robots is that a certain measure of compliance is built into the end effector by the air cushion effect, i.e., the gripping force is essentially constant and controllable for any size object (any opening of the gripper) and is a function of the end effector design and the air pressure.

A compliant end effector of interesting design is used on the Amtrol Mercury robot: Two fingers are used and each finger consists of a hollow plastic tube closed at the end and connected at the wrist to an air supply; the outside of each finger is corrugated like exaggerated folds of skin. When air pressure is applied, these corrugations open out, causing the finger to turn inward and grip an object. The mechanisms we've developed and describe here perform a similar function but are based on a different concept. They are simpler to make, easier to modify, and more universal in application.

PRINCIPLES OF THE STRUT MECHANISM

Consider a strut or structural member that is slender, so that its length is much greater than its smallest cross-sectional dimension. Such a strut is inherently flexible. Make the strut's cross section such that the ratio of the width, a, to the height, b, is large; usually $a/b > 4$. An axial compressive load placed on the strut will tend to buckle the strut in the plane of b.

Suppose two such struts are joined by the wide dimension at the end, and the end of one strut is fixed in space while the end of the other strut is subject to a pulling force. The struts will deform. Next, suppose the strut under tension contacts an object fixed in space. It will tend to conform around the object. Notice that the relatively wide struts provide stiffness in a plane orthogonal to the gripping action to prevent buckling under load.

The two-strut arrangement constitutes a finger. A gripper, or hand, is composed of two or more fingers. Figure 1 shows the configuration for two fingers. In a gripper, the ends of the struts to which the actuating force is applied are joined together. It is not necessary that the fingers of a gripper be identical, although it is often desirable to have a balanced gripping action. A gripper can be constructed to act in a manner similar to the human hand using a stiffer and possibly wider finger arrangement on one side and two or more fingers on the other side in the same way the human hand uses an oppositional thumb. It may be desirable for the stiffness of the thumb to match the combined stiffness of the fingers.

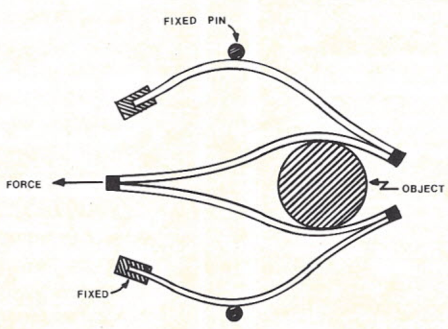

Figure 1. The basic Compliant Mechanical Gripper. Four struts made of metal or plastic are joined as shown. Two ends of the outer struts are fixed. A mechanical force is applied to the center joint, causing the inner struts to close around an object. Fixed pins are used to set limits on the motion of the struts.

The use of pins, restrainers, or guides can alter the shape the struts will follow when subjected to a pulling or pushing force. For example, the use of the restrainers shown in Figure 1 prevents the struts from deforming outward at the point of restraint, and so modifies the shape of the struts when subjected to a pulling force. It also modifies the amount of pulling force required for a given deflection. More than one restrainer can be employed to produce specialized gripping actions. The restrainers can be pillars, and several pillars can be employed. The gripping action can be altered by repositioning the struts to bear on different pillars. In this way the same gripper can be altered at will to grip different types of objects or perform different functions. Alternatively, the orientation of the fixed end of a strut can alter the gripping action. The hand shown in Figure 1

has restrainers positioned so that the hand can grip curved objects.

Since a single pulling or pushing force activates the hand, the mechanical contact between the hand and the mechanism to which the hand is connected (often called the wrist) is very simple. For example, a pulling force can be obtained with a cable or rod that has a swivel arrangement at the end similar to that used on leaders in fishing tackle. In this way the connection between wrist and hand can be rotational, and the hand can then be used for assembly work such as installing machine bolts.

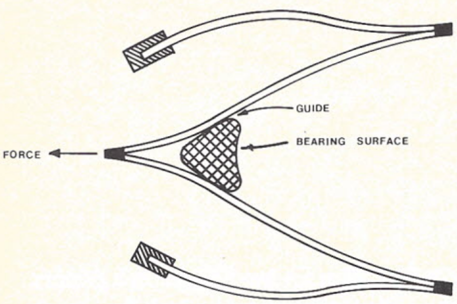

Figure 2. Modification of the Compliant Mechanical Gripper with a guide block. The guide block constrains the inner struts of the gripper and provides a bearing surface for contact with objects.

A restrainer, or guide, between the fingers of the hand, as shown in Figure 2, can alter the gripping action. It can also act as a bearing surface to aid in holding an object. Another way of achieving specialized gripping actions or to increase rigidity is to use more struts per finger, an arrangement that increases the lateral pressure obtainable with a gripper. Alternatively, the unloaded shapes of the struts can be designed for specific applications instead of being essentially straight and untwisted.

The material used for the struts can be plastic, fiber glass, metal, wood, or almost any other material that is semirigid and springy. For heavy-duty applications, or in high-temperature environments, spring steel would be satisfactory. To increase gripping action, it is often desirable to cover the surfaces that come into contact with the objects to be gripped with a compliant material. Surgical rubber has been found satisfactory for light-duty applications involving small grippers. A prototype gripper using nylon baling ties and surgical rubber bearing surfaces is shown in Photo 1. Notice the pillars that act as restrainers to change the gripping action.

A simple snap-together design suitable for plastic injection molding is shown in

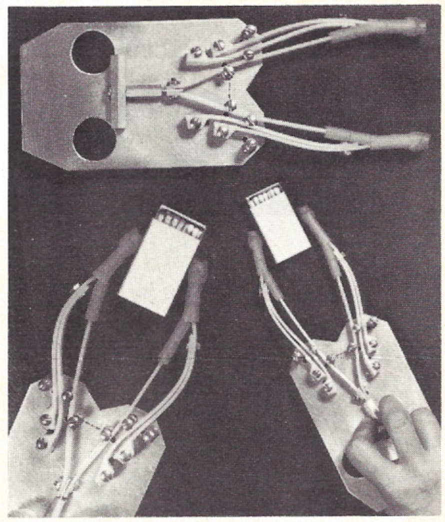

Photo 1. A prototype of the compliant mechanical gripper was constructed to illustrate its operation. An aluminum plate provides a fixed reference plane. Guideposts and attachments to the plate are provided by machine screws. The struts for this prototype were made from the standard plastic cable baling ties available in any well-equipped prototype electronics laboratory. The cable ties were drilled to accept the machine screws. Surgical rubber tubes cover the machine screws that join the two struts of each finger.

Figure 3. The struts attempt to return to their original shape when the hand is unloaded, thus opening the gripper. A pulling force causes the outer struts to slide in the channels and push the finger tips away from the axial pulling force, while the inner struts pull the finger tips toward the axial force. This causes the fingers to curl inward to grip an object as required.

To grip hollow objects such as a pipe from the inside requires a hand activated by a pushing force to deform the struts outward, but the design of the hand is basically unaltered.

The mechanism discussed can be constructed with a ratchet and trigger so that the gripping force can remain constant until the applied force is removed.

APPLICATIONS

The gripper described in this article has many applications. In addition to the obvious use as a robot end effector, the gripper could be used as a prosthetic hand. The compliance would be a major advantage; since the mechanism requires no lubrication and can be immersed in liquids, the prosthesis could be used where other devices fail (as an eating utensil, for example). The ability to alter the gripping action at will enables the prosthesis to be catholic in application. The hand shown in Photo 1 was used to drink coffee from a styrofoam cup.

The gripper's simplicity makes it inexpensive to manufacture, so it could be used in a child's toy. In fact, when some children got hold of the prototype they did not want to relinquish it, having found great amusement in picking up pots and pans and harrassing the cat.

The gripper can also be operated remotely for parts manipulation and retrieval in a hostile environment. It can be constructed of metal to withstand high temperatures and can be considered disposable if contaminated. Since all parts are exposed and need no lubrication, the gripper can be sterilized for medical applications. We believe this fundamental and versatile mechanism will find applications in many areas of robotics.

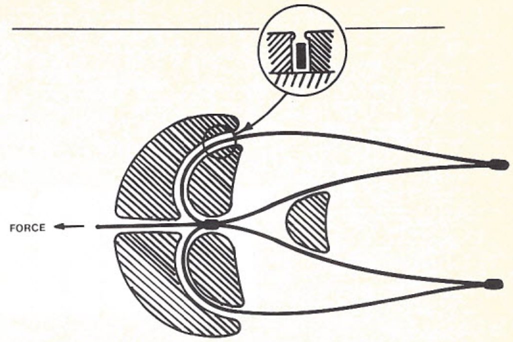

Figure 3. In actual fabrication, this Compliant Gripper could be inexpensively mass-produced from plastic injection molded parts that snap together. The cross-sectional detail shows how a channel for the finger struts can be formed.

Charactistics of the Compliant Gripper

- Compliant fingers conform to object gripped (not a parallel jaw gripper).
- Automatic return to open position.
- Self-centering.
- Remote mechanical actuation.

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THIRD-GENERATION ROBOTS: THEIR DEFINITION, CHARACTERISTICS, AND APPLICATIONS

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Industrial robots have been around for well over 20 years. The first-generation robots of the sixties were used to load and unload machines and to perform simple material transfer operations. The second-generation robots of the seventies performed more complex tasks such as tending multiple machining centers and welding automobiles. The third-generation robots of the eighties are performing such highly sophisticated tasks as tactile inspection, free-hand machining, adaptive arc welding, and assembly operations.

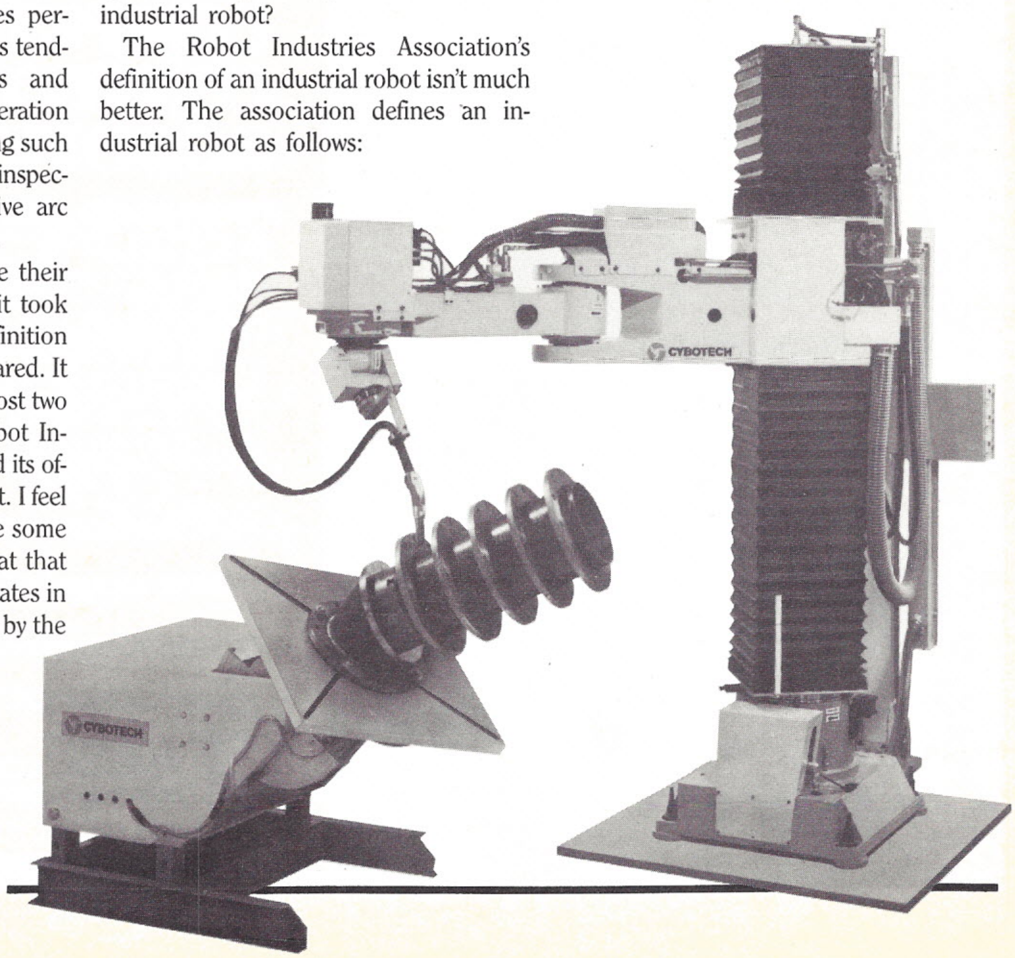
Although industrial robots made their formal debut in the early sixties, it took almost 20 years until a formal definition of the term "industrial robot" appeared. It wasn't until January 1980, after almost two years of deliberation, that the Robot Industries Association (RIA) published its official definition of an industrial robot. I feel that the RIA was compelled to take some kind of action to ward off the threat that Japan was surpassing the United States in its use of industrial robots, because by the late seventies, Japan claimed to have over 50,000 robots installed and in operation, while the United States had less than 2000.

But who really held the upper hand?

It all depends on how one defines the term "industrial robot." The Japanese define it as "any device that replaces human labor." That's an awfully broad definition. Does that mean that one can call an automatic dishwasher or an air cylinder that pushes parts into a box an industrial robot?

The Robot Industries Association's definition of an industrial robot isn't much better. The association defines an industrial robot as follows:

"An industrial robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or other specialized devices through variable



programmed motions for the performance of a variety of tasks."

All the RIA definition really says is that an industrial robot is a device that performs a variety of tasks by moving around. The definition makes no mention of the robot's ability to be interfaced with its working environment, its ability to control or synchronize itself with the equipment with which it is working, or its ability to react to changes within the process it is performing. Consequently, the RIA definition of an industrial robot simply doesn't apply to the "third-generation robots of the eighties."

What, then is a "third-generation industrial robot"? To answer this question, one must examine and compare the characteristics of first- and second-generation robots.

FIRST-GENERATION ROBOTS

First-generation robots were very "low-technology" devices that did not operate under servocontrol. Consequently, they were often referred to as "slam bang" robots, a term that referred to the sound these devices made as their arms slammed and banged into hard, mechanical stops, which were used to restrict their movement.

Almost all of the first-generation robots were pneumatically powered. Their controllers usually consisted of air logic elements, indexing drums with cams that activated air valves, or relays that operated air solenoid valves.

SECOND-GENERATION ROBOTS

Second-generation robots were medium-technology devices that operated under servo control. Consequently, they could be programmed to move from point to point or in a continuous path. Their controllers were either programmable logic controllers or minicomputers, and they were programmed on line by means of a hand-held push-button pendant.

Second-generation robots had dedicated application software, which meant that if the robot was performing a task such as machine loading, it would be extremely difficult and costly to use it for another task like resistance welding. To do so would require substantial modifications to the robot's control system and operating software.

Second-generation robots also had limited diagnostic capabilities. Typically, they used indicator lights to alert the operator to a malfunction. It was then up to the operator to diagnose the malfunction by either observing the robot's actions or searching through troubleshooting charts and schematics.

THIRD-GENERATION ROBOTS

As stated earlier, third-generation robots perform operations that are beyond the capabilities of first- and second-generation robots. The following is my own definition of a third-generation robot:

"A reprogrammable, computer-controlled machine that can be programmed to perform a variety of tasks normally accomplished by human beings and capable of being interfaced with its environment to interact intelligently with the equipment with which it is working, and able to adapt its operation within the overall process through the acquisition of sensory data."

Now that we've established a definition of third-generation robots, let's see how their characteristics differ from first- and second-generation robots.

THIRD-GENERATION CHARACTERISTICS

Third-generation robots are high-technology devices. They operate under servo control and can be programmed to move in both a point-to-point and a continuous-path fashion. They can be programmed either on line by means of a hand-held push-button pendant or off line via a keyboard and CRT screen. Third-generation robots use high-level programming languages and can be interfaced with a CAD database or a host computer for uploading and downloading programs.

Their control systems can process sensory data to adaptively control movements to compensate for changes in part fit-ups, part location, and part orientation. By using sensory feedback data and by being interfaced to a CAD database or host computer, third-generation robots can provide the operator with messages describing the nature and location of a malfunction.

THIRD-GENERATION APPLICATIONS

Today, third-generation robots are being used to perform such tasks as adaptive arc welding, in which the robot uses vision or through-the-arc sensing to locate a weld joint and obtain information to guide it through the welding process.

They are used to drill and route both aluminum and composite components for aerospace vehicles using both off-line programming techniques and visual sensing.

Third-generation robots are also being used for nondestructive testing of aerospace components, especially those having compound contoured surfaces. By interfacing to a CAD database containing geometric data for a specific part and using tactile sensor technology, third-generation robots can execute an inspection routine in a partially self-programmable manner.

Through off-line programming techniques, these robots can perform such intricate assembly tasks as the complete assembly of wire harnesses for aircraft.

THE NEXT GENERATION

Third-generation robots are *real* and they are in operation *today*. But what about the future? What about fourth-generation robots? What will they be like?

In my opinion, fourth-generation robots will probably be nonmetallic devices. As prices for high-technology material continue to drop, we'll probably see robots built from filament-wound material or graphite composites. In addition to lighter weight, these robots will be more rigid than the third-generation robots of today. However, these fourth-generation robots will be very mechanically inaccurate, "sloppy" if you will. But they will use visual and tactile sensing to give them the "true" eye-hand coordination they will need to perform the most intricate of tasks.

By the 1990s, microprocessor technology, control algorithm development, and specialized software will probably reach a point where the only limitations for applying industrial robots will be those of the human imagination.

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A CRITIQUE OF THREE GRIPPER DESIGNS

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New York Institute of Technology
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Artificial Intelligence Laboratory
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Source ID: BCE252

Gripper technology has advanced from two opposing jaws to multifingered human hand simulators. However, most grippers currently used are still primitive in design and can generally grasp only predefined objects. The trend in gripper design is toward either multipurpose grippers or those that can easily be modified for various tasks.

Photo 1 shows a general-purpose gripper. Some specifications, however, were set before the designing began. It should be able to lift heavy loads, push objects when its jaws are closed, be maneuverable with the existing robotic arm, and grasp many different objects. This gripper's primary use is for research on a hydraulic/electric arm.

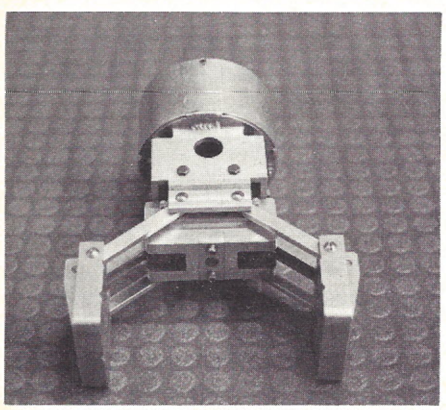


Photo 1. A general-purpose stepper motor controlled gripper. Any jaw opening distance can be set under software control without hard tooling changes.

The jaws can grasp objects up to 7 in. (17.7 cm) in diameter. A unipolar stepper motor with a holding torque of 36 oz.-in. (254 mNm) and a step angle of 7.5 degrees provides the gripping force. Gear reduction is added so that one revolution of the motor shaft produces 0.25 in. (0.64 cm) of jaw travel.

The parallel moving jaws are constructed of aluminum and brass. Since the jaws move in a parallel fashion, they are able to grasp many differently shaped objects. With the addition of perpendicular grooves in each jaw, they can grasp such objects as a cylinder, a sphere, a spheroid, a cube, objects with parallel sides, and nonconforming shapes. With the motor and gear train mounted, the unit weighs approximately 8 lbs. (3.5 kg). This is quite heavy for an end effector and requires a powerful arm to manipulate it.

The stepper motor is controlled by an SSA-1027 drive chip and accompanying circuits. The arm/gripper control computer must send out a pulse train and a direction-of-rotation bit to control the gripper. It must also receive positional feedback from an incremental optical encoder that is mounted on the output of the gear reduction shaft. The gear reduction arrangement used to multiply stepper motor torque is shown in Figure 1.

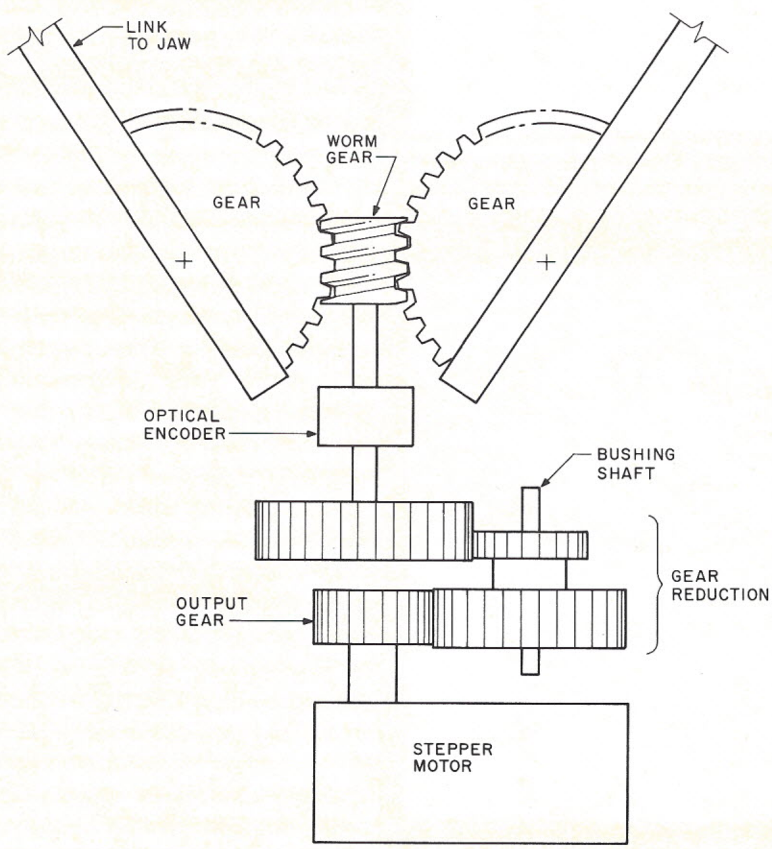


Figure 1. Mechanical schematic of the general-purpose gripper shown in Photo 1.

Photo 2 shows another general-purpose research prototype gripper. This one weighs only 2 lbs. (0.9 kg). Its present configuration includes modifications that allow it to grasp both integrated circuits and a needle-holding fixture (Photo 3). There are rubber pads on the edges of the integrated circuit gripping area. The dowel that protrudes from one jaw is used to center the needle fixture. Gripper movement is supplied by a 12-VDC, 5000-rpm motor through a 75:1 gear reduction. The output of the gearbox is then attached to a pinion gear that moves the rack gear mounted jaws. A current-limiting resistor is used in series with the motor to allow a locked-shaft condition that occurs when the jaws are kept closed.

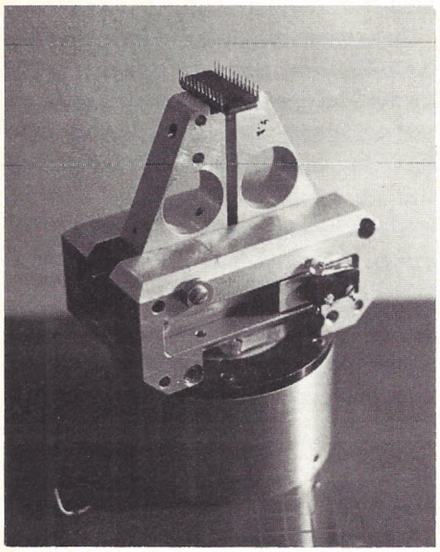


Photo 2. A fixed-gap gripper that uses feedback from a limit switch (see Figure 2) to override activation of its motor. Retooling the jaw gap requires manual adjustment of the switch.

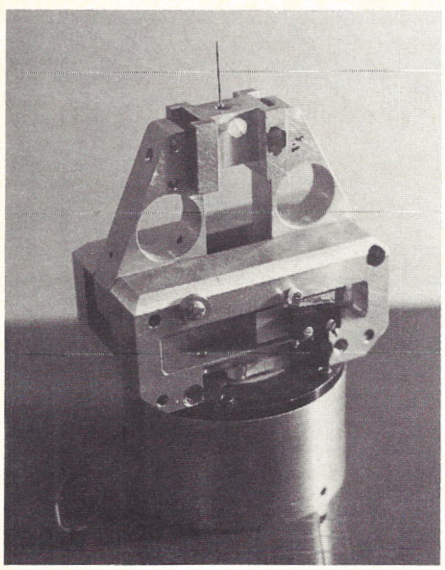


Photo 3. The fixed-gap gripper of Photo 2 shown holding a needle in a fixture.

This gripper is constructed of aluminum. Because these jaws also move in a parallel manner, they can easily grasp an integrated circuit. The drive motor operates from an output bit on the robot's control computer. If the bit is set high, the gripper closes; if the bit is set low, it opens. This type of operation is typical of most assembly robot end effectors: they are either on or off, open or closed. A limit switch is used to detect end of jaw travel and then disable the motor (Figure 2). Because the limit switch is the only type of positional feedback used, the jaws will always apply the same pressure against any object they are trying to grasp. Adjusting the limit switch mechanically sets the width of the jaw opening.

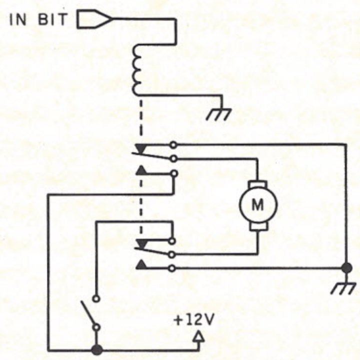


Figure 2. Activation circuit with limit switch for the gripper of Photos 2 and 3.

Photo 4 shows another integrated circuit package gripper. This one weighs less than 1 lb. (0.4 kg) and is also constructed of aluminum, except for the steel integrated circuit contact area. Jaw travel is supplied by a solenoid; there are thus only two possible positions—open or closed. The jaws pivot at the outermost edges (Figure 3). Dowels on the inner edges link both jaws to a lateral bar that is then attached to the plunger of the solenoid. A single bit can also control this gripper. When the bit goes high, the solenoid pulls the plunger down, overcoming the return spring. When the bit goes low, the return spring pulls the jaws open.

The last two grippers can do the same task of grasping dual in-line integrated circuit packages as the first. They are less general purpose because they must be reconfigured to accommodate different width packages. The second gripper closes its jaws to the proper width as programmed by the limit switch, while the third has an alternate set of spacing holes, which allow

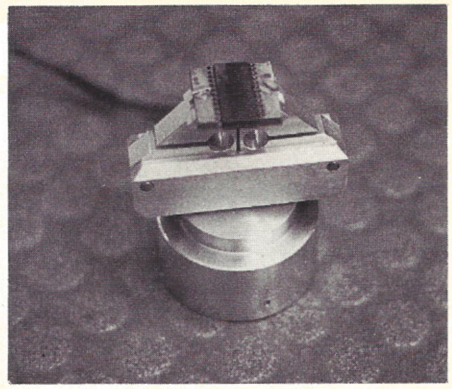


Photo 4. A solenoid-operated gripper, the crudest, lightest, and least expensive of the configurations shown here. Activating the solenoid causes the jaws to come crashing into their physical limit stops. Retooling requires adjusting the limit stops.

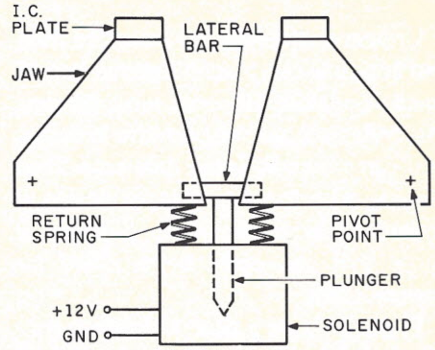


Figure 3. Mechanical schematic of the solenoid gripper seen in Photo 4.

for a smaller width. The third one can also use a different set of steel integrated circuit graspers, such as those that would be necessary for 16-pin vs. 20-pin packages. Simple tooling to different parts is necessary with these designs: readjusting the limit switch in gripper #2 and refabricating a small part in gripper #3.

Retooling a robot with a different end effector is very inexpensive when compared to the overall cost of the robot and its work cell environment. However, to the small company, any avoidable expense is too much. Thus, the trend is toward multipurpose and easily reconfigurable grippers, and even the expensive, complex handlike manipulators. In comparing the three forms of gripper design, the one-time expense and weight penalties of a more general-purpose gripper may prove more cost-effective in the long run if tooling changes are frequent.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

74	84	94
Excellent	Good	Fair

Continued from page 6

20–22 May. Introduction to Programmable Controllers. Bowling Green State University, Bowling Green, OH. Contact: Judy Jennings, School of Technology, Bowling Green State University, Bowling Green, OH 43403, telephone (419) 372-2436.

This program, cosponsored by the university and General Electric Supply Co., will feature sessions on programmable computer basics, micro and mini personal computer hardware, programming, communications, and retrofit vs. new PC installation. Hands-on practice will also be offered.

21–22 May. CIM Strategies for Competitive Batch Manufacturing. Hyatt Regency Hotel, Dearborn, MI. Contact: Sharilyn Shampine, Program Administrator, Computer and Automated Systems Association of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 386.

Topics to be covered in this seminar include achieving CAD/CAM benefits using MRP II controlled cellular manufacturing, design techniques for manufacturing cells, using group technology to obtain just-in-time benefits in a batch environment, and rationalized factory automation and plant layout.

22 May. The Robotic Assembly Work Cell. Ontario Robotics Centre, Peterborough, Ontario. Contact: Susan Harvey, Workshop Registrar, Ontario Robotics Centre, 743 Monaghan Rd., Peterborough, Ontario, Canada K9J 5K2, telephone (705) 876-1611 (Peterborough) or (416) 675-4363 (Toronto).

This workshop is directed toward companies and individuals seeking a practical introduction to the robotic assembly process. It will be of specific interest to managers and engineers considering the purchase of a robotic assembly work cell now or in the near future.

22–23 May. Writing Better User Manuals. Marriott Oak Brook Hotel, Oak Brook, IL. Contact: Registrar, Battelle/BSSP, 4000 N.E. 41st St., Seattle, WA 98105, telephone (206) 527-0542 (in Washington) or (800) 426-6762.

The seminar, worth 1.3 continuing education units, will focus on the design and evaluation of user-friendly manuals. Features to be discussed include page layout, screen displays, content hierarchy, systematic review, appropriate practice, and glossaries.

30–31 May. CAD/CAM for the Small Manufacturer. Contact: Judy Jennings, School of Technology, Bowling Green State University, Bowling Green, OH 43403, telephone (419) 372-2436.

Jointly sponsored by the university and Anilam Electronics Corp., the workshop will focus on CNC programming, CAD/CAM equipment, programming, and post processor interfacing to machine tools. Hands-on experience offered will include design geometry, CNC programming practice, and machine-tool setup and operation through post processor software.

30 May–1 June. Computer-Aided Design in Magnetics. Lory Student Center, Colorado State University, Fort Collins, CO. Contact: Monika S. Renner, Infolytica Corp., 1500 Stanley St., Suite 430, Montreal, Quebec, Canada H3A 1R3, telephone (514) 849-8752.

This short course will address analysis methods for CAD in magnetics, magnetic material representation, computational models and problem setups, formulation of field problems, and post processing of field solutions.

JUNE

3–5 June. 1985 Eastern Design Engineering Show and ASME Conference. Bayside Exposition Center, Boston, MA. Contact: Show Manager, Eastern Design Engineering Show, Cahners Exposition Group, 999 Summer St., Stamford, CT 06905, telephone (203) 964-8287.

Conference organizers describe the conference as "the first such East Coast event since such new technologies as CAD/CAM and composite materials have revolutionized the design engineering field." An outgrowth of the 32-year-old national show, the conference will have the same goals: the design of new products and the redesign of conventional products with concentration on improving the productivity of design engineers.

The design engineering division of the American Society of Mechanical Engineers will sponsor a program covering areas that have developed as the result of advances in computer technology, such as CAD/CAM, finite element analysis, composite materials development, and artificial intelligence and expert systems.

3–6 June. Robots 9. Cobo Hall, Detroit, MI. Contact: RI/SME Public Relations, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

Almost everything that can be said and seen on the subject of robots will be offered at Robots 9 when 80 or more robotics experts discuss new breakthroughs in systems software, remote applications, vision, intelligent controls, management perspectives, and R&D. Other sessions will consider new developments in mechanical and

Calendar

electronic assembly, robot programming languages, safety, aerospace applications, human productivity implications, robot design, and justification and decision making.

In addition, there will be an exhibition of more than 250 robots and robotic systems demonstrating welding cells, laser processing, water-jet cutting, material handling, assembly, gantry applications, and other manufacturing operations. Many of the systems will be equipped with the latest vision and tactile sensors, new controls and positioning devices, and end effectors and tooling.

6–7 June. Workshop on Robot Standards. Ponchartrain Hotel, Detroit, MI. Contact: Leonard Haynes, A123 Metrology Building, NBS, Gaithersburg, MD 20899, telephone (301) 921-2181.

The National Bureau of Standards and the Navy's Computer-Integrated Manufacturing Technology Program will sponsor a workshop on robot standards in conjunction with the Robots 9 conference. Planned topics include control system interfaces to robots, sensors, databases, and high-level control systems; mechanical interfaces to grippers and other end effectors; programming languages and environments; measures of performance; and human interfaces.

The workshop is cosponsored by the Robotic Industries Association, the American Society for Testing and Materials, the Institute for Electrical and Electronic Engineers, the American National Standards Institute, and the Electronic Industries Association.

10–14 June. Robot Manipulators, Computer Vision, and Intelligent Robot Systems. The University of Stirling, Stirling, Scotland. Contact: Director of the Summer Session, Massachusetts Institute of Technology, Room E19-356, Cambridge, MA 02139, telephone (617) 253-2101.

The aim of this course will be to prepare the participant for the sophisticated methods soon to be employed in advanced automation. Emphasis will be placed on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation. The use of existing industrial robots and binary vision systems will be covered also.

12–15 June. 1985 Rochester Forth Conference. University of Rochester, Rochester, NY. Contact: Maria Gress, Institute for Applied Forth Research, Inc., 70 Elmwood Ave., Rochester, NY 14611, telephone (716) 235-0168.

The focus will be on software management and engineering, and invited speakers will discuss the use of Forth in large projects, modifications to the language aimed at improving productivity, and contrast its use in business and scientific environments. Papers to be presented will cover various aspects of implementing and applying Forth, including robotics, graphics, Forth chips, and real-time systems.

The final day of the conference will be open to the public at no charge, and will be devoted to panel discussions and presentations by Forth vendors.

18–20 June. Canadian Robotics Show. International Centre of Commerce, Toronto, Canada. Contact: Ron McCreary, Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800, or Hugh F. Macgregor & Associates, 360 Consumers Rd., Willowdale, Ontario, Canada M2J 1P8, telephone (416) 491-9656.

This new event is a response to the Canadians' rising interest in robotics, which is creating new marketing opportunities for U.S. robot suppliers, according to an RIA spokesman. Running concurrently will be the fourth annual Canadian CAD/CAM show. Also, some of the exhibitors from the Robots 9 show are expected to display their products at the Canadian Robotics Show.

18–20 June. AMS '85. O'Hare Exposition Center, Rosemont, Il. Contact: AMS, Cahners Exposition Group, 999 Summer St., Stamford, CT 06905, telephone (203) 964-0000.

The fifth annual Advanced Manufacturing Systems Exposition and Conference will feature an "automation island," a completely automated and computerized manufacturing system in actual operation. Set off in a large area on the exhibit hall floor, the island will include such equipment as automated production robots; assembly machinery; a guided vehicle system for materials transfer; and computerized identification, information processing, and control equipment.

24–27 June. Fourth International Symposium on Unmanned Untethered Submersible Technology. University of New Hampshire, Durham, NH. Contact: Carol Bryant, University of New Hampshire, Marine Systems Engineering Laboratory, PO Box G, Durham, NH 03824, telephone (603) 749-6056.

This symposium will cover subjects such as acoustics/communications, imaging, control dynamics, artificial intelligence, data sources/

Calendar

sinks, and knowledge-based guidance. The emphasis will be on stimulating informal interaction among the participants. A one-day classified session is also planned.

27–28 June. Writing Better User Manuals. Marriott Oak Brook Hotel, Oak Brook, IL. Contact: Registrar, Battelle/BSSP, 4000 N.E. 41st St., Seattle, WA 98105, telephone (206) 527-0542 (in Washington) or (800) 426-6762.

The seminar, worth 1.3 continuing education units, will focus on the design and evaluation of user-friendly manuals. Features to be discussed include page layout, screen displays, content hierarchy, systematic review, appropriate practice, and glossaries.

27–28 June. First Annual Workshop on Robotics and Expert Systems. Johnson Space Center, NASA, Houston, TX. Contact: Dr. Fred King, Registration Chairman, Ford Aerospace/M4B, PO Box 58487, Houston, TX 77258, telephone (713) 280-6868.

The workshop, cosponsored by the Robotics and Experts Systems Group and ISA Clear Lake Galveston Section, will feature technical papers on expert systems, industrial robotics, computer algebra, AI for man/machine communications, teleoperations and space robotics, sensors and vision, distributed AI, and automated programming. There will also be tutorials on expert systems and industrial automation.

JULY

8–12 July. Robot Manipulators, Computer Vision, and Automated Assembly. Massachusetts Institute of Technology, Cambridge, MA. Contact: Director of the Summer Session, Room E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139, telephone (617) 253-5863.

This short course in industrial robotics is being offered under the auspices of MIT's Artificial Intelligence Laboratory. The 57 topics to be covered fall under the general headings of robot manipulators, computer vision, automated assembly, applications, and systems components. The emphasis of the course will be on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation.

SEPTEMBER

6–8 September. International Personal Robot Congress & Exposition. Moscone Center, San Francisco, CA. Contact: Sharon D. Smith, Chair, IPRC '85 Organizing Committee, 8822 S. Martin Lane, Conifer, CO 80433, telephone (303) 674-5650.

The second annual IPRC, expected by the organizers to attract over 2500 personal robot enthusiasts, will feature seminars on personal robot software and hardware, human services, robots in space, the business of personal robots, and personal robots in education. There will also be an exhibit by leading commercial manufacturers of personal robots, sensors, and related equipment. In addition, there will be displays by personal robot developers who have created their own robots in workshops and garages.

Letters

A ROBOT IS A ROBOT

Your editorial in the March issue seemed to indicate a trend away from coverage of the "personal" robots so as to more fully cover the industrial types. I would guess that a large proportion of your readership is primarily interested in the personal robot, and I surely hope that this coverage isn't to be phased out. Yours is about the only source for information in this area, and would be greatly missed were it to be curtailed.

Yours very truly,
Paul Swan
2930 Randy Ln.
Dallas, TX 75234

Robotics is a varied and far-ranging field. Since Robotics Age *was founded in 1979 we have tried to cover every aspect and application of robotic technology, from industry to medicine to basement experimentation. We have watched and reported on developments in the relatively new commercial area of personal robotics, and we intend to keep doing so. The technical articles that are the magazine's lifeblood come from every area of robotics.*

Joseph Engelberger, a pioneer in industrial robotics and an enthusiast of personal robotics, has said that a robot is a robot, whatever its application. The fundamental challenge is the same: to combine hardware, software, mechanical, and electrical engineering principles to design systems that can duplicate—or improve upon—human effort. Or to do work humans either can't or don't want to do.

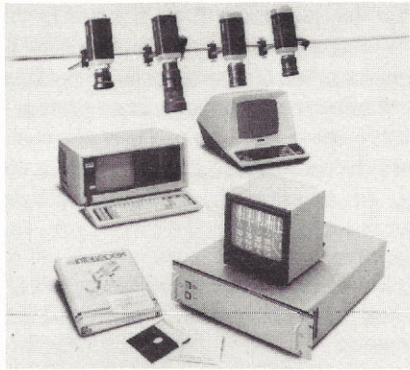
Robotics Age *will indeed be giving more attention to industrial robotics than it has in the past, but we believe this represents an expansion of interest and not a turning away from personal robotics. The magazine remains as it was originally conceived: the Journal of Intelligent Machines.*

New Products

Computer Vision System

The IntelleVue™ 200 Computer Vision System, described as a low-cost solution to the need for sophisticated yet flexible vision systems, has been introduced by Intelledex. IntelleVue 200 can perform stand-alone inspection applications or work with other automation equipment for guidance in parts handling and assembly tasks. It is available as a plug-in option for all Intelledex robots.

The system is programmable off line with a simulator, can be used with fixed or wrist-mounted cameras when working with robots, and accepts plug-in options for memory or function expansion. It is compatible with SECS II protocol.



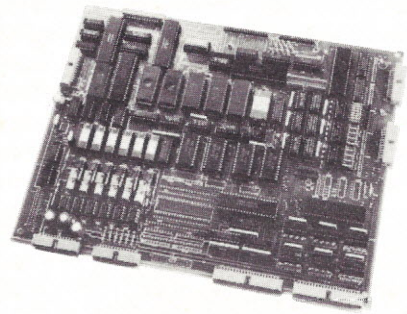
IntelleVue 200 offers a complete set of grey scale and binary vision-processing algorithms. Features include windowing, connectivity analysis, pixel counting, and special algorithms for character recognition of ANSI standard fonts OCR-A and OCR-B. The system, which runs on VISION BASIC,™ can be programmed either with a terminal or an IBM-compatible personal computer on line or off line.

IntelleVue 200 can be used for applications that require part recognition and orientation, inspection, measurement, and robot guidance. These include use with semiconductor test and processing systems, integration with robots in assembling disk drives, and inspecting printed circuit boards at various stages of the production process.

For more information, contact: Rollie Woodcock, Intelledex, 4575 S.W. Research Way, Corvallis, OR 97333, telephone (503) 758-4700. Circle 40

Modular Motion Controller

A new generation of Robo-Con, a modular motion controller, has been introduced by Kurt Manufacturing. The controller supports data network communications capabilities with IBM-compatible personal computers and interfaces with CAD/CAM systems. The basic starter package comes with 34 Kbytes of RAM, but the memory capacity can be increased to 1024 Kbytes. The company describes Robo-Con as practical and affordable for small to large applications and simple enough to be integrated with a minimal amount of electrical interfaces and communications software.



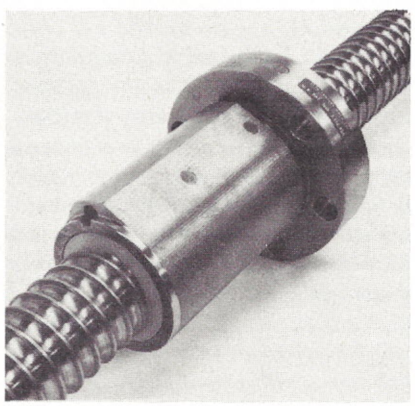
The controller has many features. Part programs can be created on tape prep systems or personal computers and downloaded to the Robo-Con on a local or remote communications basis. Motion programs can be taught in either point-to-point or continuous-path operational modes. Software is available for robotics, including material handling, spray painting, coating, gluing, and welding, as well as flame cutting, woodworking, laser cutting, metal spinning, coordinate measuring, and NC machines. Other software options include scaling, editing, circular interpolation, tool wear compensation, branching, looping, subroutines, and network protocols.

For more information, contact: David Olson, Kurt Manufacturing Co., 5280 Northeast Main St., Minneapolis, MN 55421, telephone (612) 572-1500. Circle 41

Ball-Bearing Lead Screws

A line of ballbearing lead screws, both precision-ground and the commercial thread type, is available from 20th Century Machine. The ballscrews are said to provide accurate and dependable linear motion for applications including machine tools, robots, precision positioning tables, and instruments. They are described as particularly well-suited for use in designs that are subjected to high-speed and/or high-load conditions.

The ballscrew threads are precision machined rather than rolled, producing deeper threads to maximize unit load and life. They provide linear travel accuracy based on thread-length tolerances under 0.003 in. per foot of length, cumulative.



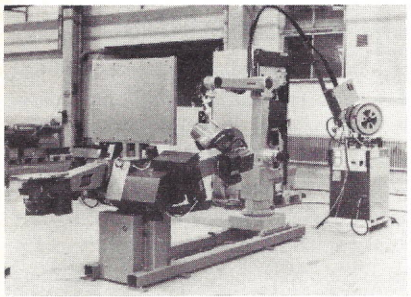
They are straightened to 0.002 in. T.I.R. for lengths up to 4 ft., to 0.004 in. for lengths of 4 to 10 ft., and to 0.006 in. for lengths over 10 ft. The concentricity of the journals to the screw is held to within 0.002 in. T.I.R.

The ballscrews use a patented, internal ball return nut rather than an external ball return tube to reduce the possibility of a tube's bursting. The company's screws feature a ball return track made by gun-drilling, EDM, and other techniques. Two standard nut configurations are available, round and cam-shaped (for replacing tube type units).

The company offers lead screws with a standard error of less than 0.0005 in. per foot of length. There are four designs, with diameters up to 6 in. and lengths up to 60 ft. Super-precision designs have thread-lead tolerances of 0.0002 in. per foot or less.

For more information, contact: Bud Hulewicz, Director of Marketing, 20th Century Machine Co., 6070 E. Eighteen Mile Rd., Sterling Heights, MI 48078, telephone (313) 536-0260. Circle 42

New Products



Robotic Welding Station

A robotic welding station for medium-sized workpieces has been introduced by ESAB. The ORBIT 160B can handle workpieces up to 350 lbs. (160 kg), including fixture. The new station integrates robot movement with the servocontrolled ORBIT positioner and also controls the welding equipment.

Because the positioner is programmed and guided from the robot's computer, the same system controls all nine servo axes—five of the robot's and four of the positioner's. This synchronization allows the workpiece to be manipulated at the same time the welding gun is being positioned. In addition, ORBIT 160B can move the workpiece and weld at the same time and can handle nonstop welding on joints that normally require different sequences, separated by positioning movements. Adaptation of the positioner's rotation speed and position to the robot's permits consecutive welding of geometrically complicated joints.

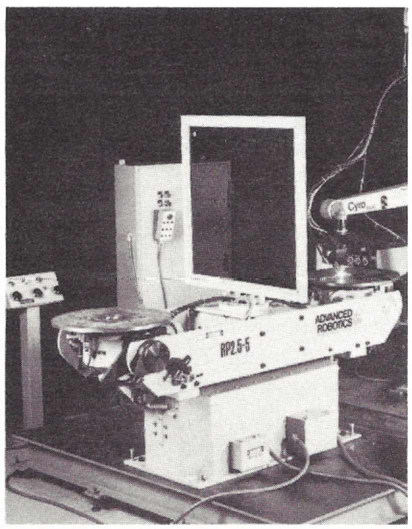
The servocontrolled drive units produce movement that is highly precise and extremely fast, the company says. Repetitive accuracy is ±0.004 in. (0.1 mm) measured at a radius of 19.68 in. (500 mm). The ORBIT's movement pattern rotates the workpiece around its own center of gravity, producing a tighter working range and maximizing the robot's reach.

A screen separates the ORBIT 160B's two stations. The robot can weld continuously on one side of the screen while the operator, protected from glare and sparks, loads and unloads parts on the other. By changing fixtures, a number of different workpieces can be welded at the same station, and since station shifting requires operator acknowledgment, the operator is in full control.

For more information, contact: ESAB North America, Inc., Robotic Welding Division, PO Box 2286, Fort Collins, CO 80522, telephone (303) 484-1244. Circle 43

Robotic Arc-Welding Work Cell

A robotic arc-welding work cell said to maximize joint accessibility has been introduced by Advanced Robotics Corp. The Cyro® 1000 RP Five-Axis Positioner is a twin-table, pneumatic microprocessor-controlled positioner that allows the operator to load or unload parts on one end while the robot is welding on the other. The operator stays outside the robot's work envelope. The positioner provides high-speed parts transfer, reducing the robot's waiting time and increasing work-cell utilization.



There are five axes: two tilt, two rotate, and one index. Part accessibility is provided by eight fully programmable stops in rotate and four in tilt. The cell also offers precise control of indexing motions to allow faster indexing between welds. The Cyro C-30 control commands all position motions. The positioner uses an independent platen and control, allowing the operator to jog the table manually to facilitate loading and unloading part assemblies.

The Cyro 1000 provides 1000 mm reach with a ±0.2 mm repeatability. Software features include weld path weave, torch-angle compensation, and real-time control of weld process variables. Joint, linear, and circular interpolation and program shift and transformation are designed to simplify programming.

For more information, contact: Advanced Robotics Corp., 777 Manor Park Dr., Columbus, OH 43228, telephone (614) 870-7778. Circle 44

New Products

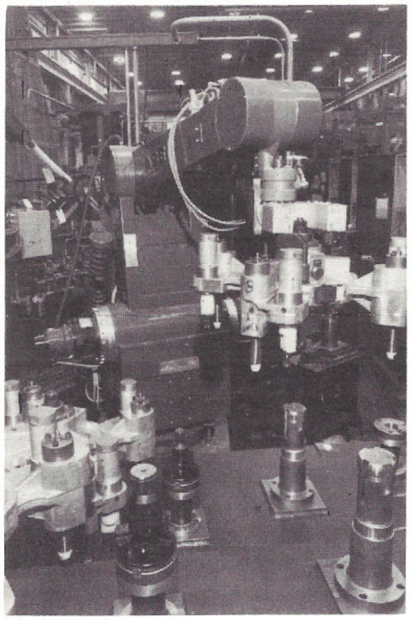
Five-Axis Robot with Gripper Fingers

LaSalle Machine Tool has announced what it believes to be the first five-axis robot with universal gripper fingers to be applied in full-scale, computer-aided manufacturing systems. The robot is described as having two personalities, a tool engineer during full-scale production and an assembly worker.

When commanded by the host computer of an automatic line, the robot takes the assembly press apart, quickly reassembling it to ready it for handling a different size part. It handles arbors and fixtures with the same "sticky fingers," as the company terms them.

After an assembly changeover, the robot picks up parts to be assembled from a pallet and places them, one at a time, in a rotating fixture mounted under a vision camera for part size verification and radial orientation. Then the robot regrips the part, swings it and inserts it into a special collet, clears the assembly machine, and signals it to begin its assembly cycle.

As the part is being processed, the robot turns and picks up another part and puts it into the orienting fixture. Meanwhile, the robot turns to regrip the completed part from the assembly machine, puts it into a take-away pallet, and turns again to grasp



the part just oriented and put it into an empty collet indexed for position for loading by the assembly machine. Once the pallet has its assembled, four-part load, the robot signals the elevator of the automatic conveyor for a take-away. The robot depends on a run of same-size parts for a repeating cycle.

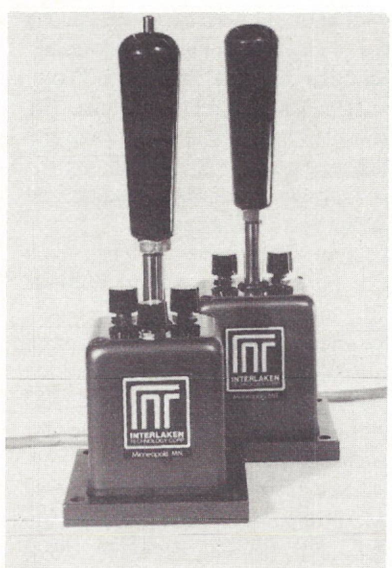
For more information, contact: LaSalle Machine Tool, 999 W. Big Beaver Rd., Troy, MI 48084. Circle 51

Force-Operated Joysticks

Interlaken Technology's new joysticks are based on force input rather than position, a feature said to improve operator feedback. One-, two-, and three-axis versions are available. Zero adjustments provide for precise zero setting in critical applications. An applied force of ± 10 lbs. creates a ± 5 VDC output from the internal electronics. The third axis is a thumb button with 0.5 lb. force and 0–5 VDC output.

The joysticks are built for industrial use. Applications include programming robots, industrial automation, and operator control of cranes, hoists, and special equipment.

For more information, contact: Interlaken Technology Corp., 6535 Cecilia Circle, Minneapolis, MN 55435, telephone (612) 944-2624. Circle 52



Literature and Brochures

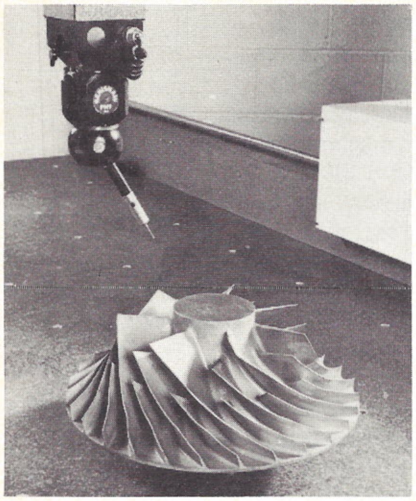
Four comprehensive databases on environment and computer/communications technologies are available by subscription through EIC/Intelligence. The new information services cover acid rain, CAD/CAM, artificial intelligence, and telecommunications. Each database consists of a complete microfiche document collection, a monthly journal with abstracts of current material, and an annual cumulative index. Contact: EIC/Intelligence, Inc., Dept. of Marketing Services, 48 W. 38th St., New York, NY 10018, telephone (800) 223-6275 or, in New York, (212) 944-8500. Circle 53

A Robot in Every Home, by Mike Higgins, editor of *Personal Robotics News,* is addressed to the questions: Why is personal robotics beginning to attract so much public attention? What can these robots do for us today and how are they likely to develop in the future? The 192-page book contains 50 illustrations and includes a brand-name buyer's guide to commercially available personal robots. Contact: Kensington Publishing Co., 6300 Telegraph Ave., Oakland, CA 94609, telephone (415) 547-7100. Circle 54

Robots in Manufacturing: Key to International Competitiveness, by Jack Baranson, is a report on the design, production, marketing, and use of robots in Japan, the United States, and four Western European countries (Sweden, Norway, France, and Italy). Topics covered include why automated manufacturing is important, why the United States is falling behind other nations, and what can be done to stem the decline in this country's competitiveness. Contact: Lomond Publications, Inc., PO Box 88, Mt. Airy, MD 21771. Circle 55

Smart Robots, by V. Daniel Hunt, is intended to clarify technological principles and industrial applications of intelligent robots as well as current developments in the field. The 400-page book is an overview, compiled from a variety of research sources including technical seminars, government-funded studies, and users of robotics technology. Contact: Technology Research Corp., 5631-L Burke Centre Parkway, Burke, VA 22015, telephone (703) 425-7949. Circle 56

New Products



Soft Scanning Inspection System

Auto-Scan, new from LK Tool Co. Ltd., was designed to measure complex contoured surfaces. A soft scanning inspection system, the Auto-Scan focuses on the increasing demand for objective and repeatable measurement of two- and three-dimensional contours within an automatic measuring capability. The system is in many cases retrofittable to already installed multiuser-controlled CMMs.

According to the manufacturer, the company's aim was to retain all the features of its earlier package, such as point-to-point data collection, data manipulation, probe compensation, curve fitting, and error calculation, while adding new features: soft scanning action of CMM for data collection, measurement of re-entrant features, closed-loop scanning path, and free space orientation of the scanning/measuring plane.

Unlike the "pecking" action of the digitizing process, to which the CMM oscillations were unacceptable, the soft scan movement flows across the component surface. The measuring action is self-determining and curves into and out of the surface profile being measured while the remaining axes continually trace movement along the plane to be scanned. The resulting machine action, the company says, is a smooth and continuous contact with the profile being measured.

For more information, contact: LK Tool USA, Inc., 1625 W. University Dr., Suite 6, Tempe, AZ 85281, telephone (602) 968-3786. Circle 49

Cutter Path Software

The XTAL Corp. (pronounced Crystal) has developed user-friendly software that enables NC and CNC machine operators to plot eight standard and two user-definable views of a cutter path immediately before postprocessing. CLPLOT is the company's latest enhancement to its FACTORYnet™ microcomputer system. FACTORYnet integrates CAD/CAM, NC/CNC, and CMM technologies, bypassing blueprints and paper tapes.

CLPLOT allows shops that are not CAD/CAM equipped to see a cutter path and determine whether changes are needed before information is sent to the NC or CNC machine. It provides a hard-copy documentation of cutter paths. The new software's menu options include six planar views, two isometric views, and two user-specified oblique projections. Each view can either center on a specific point or be plotted according to a number of scaling options, such as automatic scaling to fit a particular size paper, user-specified scale, and actual size.

Feed moves appear on a plotted cutter-path illustration as solid lines, and rapid moves appear as dashes. Cycles appear as solid lines in a color different from that used to indicate feed moves. An optional axis and part origin indicator appears in a third color. CLPLOT can be used with APT CL files in seven formats: Auto-trol (Native Format), Calma, CDC CD2000 (APT 3), CV DADDS 4, IBM (Apt AC), McAuto (Standard APT), and XTAL™ Condensed Binary. The software operates with the six-pen Hewlett-Packard 7475A plotter, which accommodates A and B size paper.

For more information, contact: Bert Locke, XTAL Corp., 12217 Nicollet Ave., Minneapolis, MN 55337, telephone (612) 894-9010. Circle 50

Continued on page 36

Advertising

Reader Service

**Correspond directly with company*

Classified Advertising

PERSONAL ROBOTS, KITS and BOOKS at discount prices. **CAL-ROBOT**, 16200 Ventura Blvd., Suite #223, Encino, CA 91436, (818) 905-0721.

RADIO-CONTROLLED ROBOT TANK PLANS. Use your home computer to program the tank's path. Optical Interface needs no wires into your computer. All parts from Radio Shack. Complete schematics, instructions, and software—$14.95. **CYNZAC ENGINEERING**, 6117 Calle Arena, Camarillo, CA 93010.

MANUFACTURING ENGINEERS. West Coast opportunity with growth firm for M.E.s experienced in robotics tooling, methods, state of the art modernization processes. Salaries and incentives commensurate to experience level. Reply in confidence to **CLD, INC.**, P.O. Box 661896, Sacramento, CA 95866.

MILLER'S WHEEL AND PINION CUTTING. Write to **DAVID G. MILLER**, 23½ E. State St., Alliance, OH 44601.

TOOL-CHANGING ROBOT HANDS

Mathew L. Monforte
Monforte Robotics, Inc.
2333 Whitehorse-Mercerville Rd.
Trenton, NJ 08619

Industrial robots used for assembly (Iron Collar Workers) are rapidly finding positions on manufacturers' shop floors throughout the world. Typical industrial assembly processes involve performing multiple tasks on one product in various states of production. In the past, the introduction of robotics has commonly demanded one task per robot since industrial robotic end effectors were usually custom-designed to perform one specific task in the assembly process. Often, a change in product design or model will warrant removal and/or replacement of the end effector in order to be compatible with current running configurations. Sensor capabilities designed into each end effector must also be considered for monitoring cell functions. The principal advantage of using robotics in assembly over other traditional methods is versatility. Although the robot can easily run a variety of motion programs, the end effector is almost always dedicated.

A tool-changing robot hand system can automatically and intelligently retool itself under the same computer control as the robot manipulator device. The introduction of such a system into the work cell offers a fresh new approach to robotics and to the task the robot is to perform. Advantages of this approach include eliminating the cost and floor space of multiple work cells, fewer line shutdowns for retooling high-cost custom-designed end effectors, and generally enhanced production. A tool-changing end effector certainly warrants consideration in most robot work cells.

DESIGN CONSIDERATIONS AND GUIDELINES

In order for a multifunctional, intelligent end effector to be practical and effective, the following guidelines were taken into consideration. The end effector must:

- be durable in construction but light in weight to be compatible with the largest selection of robots
- retain as much accuracy as possible from the host robot by having the fingertip-to-mounting clearance as small as possible
- be able to exert enough gripping force to be applicable with higher payload robots
- be able to grasp a variety of parts or tools using desired gripping forces as needed
- be able to acquire work pieces or tools in a variety of modes of pickup (our design goal was at least six distinct modes)
- be able to acquire work pieces or tools larger than maximum finger opening
- be able to retool itself under automatic control
- be able to work with parts or tools in a work cell in a manner similar to custom-designed end effectors
- be able to engage or disengage custom toolings or work tools in less than ½ second
- have a cost-effective retooling method
- have an interface method compatible with the largest selection of robots
- be as user-friendly as possible
- have a selection of sensors to monitor gripper duties
- have a selection of features to perform complex assembly

The Foreman Hand was developed to meet these design considerations. To appeal to a wide range of assembly operations, the hand's sensors and features were designed in a modular fashion. The final design outcome was a series of 16 end effectors, all meeting the design guidelines. With common internal mechanisms, the Foreman Series offers an upgrading feature: Sensors and other features can be added at any time because of their modular configuration.

The hand's main frames are constructed of magnesium, a lightweight metal, because of its strength-to-weight factor. To retain the accuracy of the host robot, the internal mechanisms were designed as compactly as possible, with a fingertip-to-mounting surface dimension of 6.90 in. The true parallel finger stroke of 3¾ in. has a maximum gripping force of 120 lbs. and operates at a range of 15–150 psi. Because they have the flexibility of six distinct modes of pickup in conjunction with the use of the adapter keys and sensors, the hands can easily handle a variety of functions intelligently—component insertions, multiple parts, large parts, small parts, odd-shaped parts, use of hand tools, and delicate parts, for example—in one continuously running work cell. The industry standard data interfaces available (including RS-232) permit end users to operate and monitor the hands through the host robot's computer and its software. The hand is just another peripheral to the robot control computer; programming languages and methods remain the same.

ADAPTER KEYS

The uniqueness of the Foreman Hand is the ability to retool itself automatically in a cost-effective manner under robot control. The adapter keys and the hand's six modes of pickup provide the flexibility to work with a variety of shaped parts or tools. (See SIX DISTINCT PICKUP MODES.)

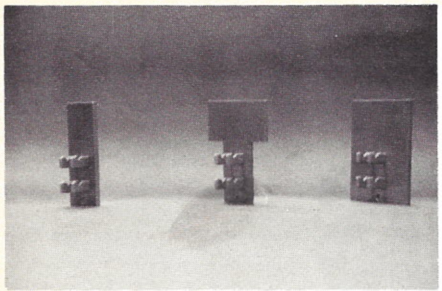


Photo 1. Adapter plates used to configure the Foreman end effector with quick-change tooling. Note the adapter keys protruding from the plates in a configuration that fits the matching locking receptacles on the two fingers of the gripper.

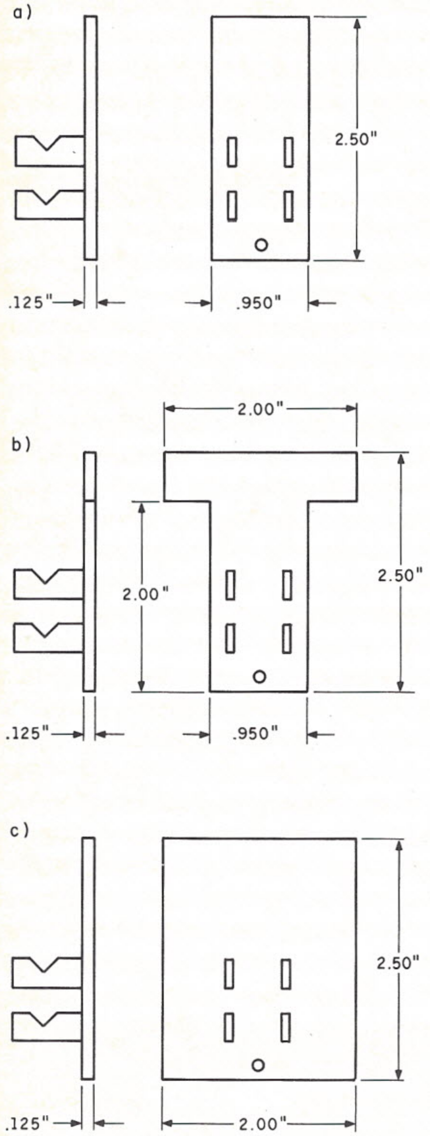


Figure 1. Dimensions of the standard Foreman adapter plates. The I-style plate (a) is about the same size as the gripper finger style (b), and O-style (c) plates have extended areas that can be used for dead-blocking the end effector against fixed, mechanical reference jigs.

The adapter keys are available in three standard sizes: T, I, and O. (See Photo 1.) The flat face of the adapter key is for mounting tools, custom-configured surfaces, sensors, mechanical devices, etc. The I style is approximately as wide and long as the hand's finger. The T style provides an extra surface for customized configurations or dead blocking, a technique of setting a mechanical limit on gripper movement to a precise position, either opening or closing. The O style provides a much larger mounting surface. Suitable for custom configurations and dead blocking, the O style provides an excellent surface for mounting a variety of off-the-shelf hand tools.

Once configured, the keys are nested for pickup by the hand. There are no dedicated nesting areas, so tooling can be placed anywhere in the work cell area within reach of the robot arm. A properly designed nest should have from 5 to 10 thousandths of an inch of freedom for the tooling to sit in. Final indexing is provided by the tool lock mechanism.

ACQUIRING ADAPTER KEYS

After the adapter keys have been nested in the robot cell, the robot must be taught a position for acquiring the keys through the following procedure:

Step 1. Set tool locks to the off (or up) position. If the robot's controller is equipped with a tool lock positive-pressure indicator, green indicates tool lock "on" and white indicates tool lock "off." If there is no indicator, the locks can be seen in their locked position when adapter keys have not been inserted into the fingers, as illustrated in Figure 2.

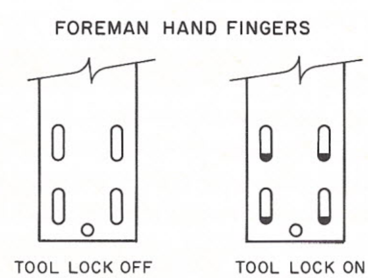


Figure 2. The receptacles for the adapter keys have a computer-activated locking mechanism shown schematically here. In the unlocked mode (left), the keys on the adapter plate move in and out of all four holes freely. In the locked mode, a precisely engineered tool lock bar is raised to mate with the notches on the adapter keys.

Step 2. Release air pressure to the hand actuator.

Step 3. By hand, open or close the fingers to a ready position (i.e., finger position prior to inserting adapter-key prongs into the hands through holes for that particular nested tool). Figure 3a shows the hand at this state.

Step 4. Move the robot arm to the tooling in such a way that the adapter-key prongs can be freely inserted into the hand finger through the holes. (See Figure 3b.)

Step 5. By hand, move the gripper fingers open and close over the adapter-key prongs. Make robot arm-position adjustments as necessary. Little or *no* drag on the adapter-key prongs constitutes a proper ready position for pickup.

(Note: The Foreman Hands are dependent upon proper positioning and repeatability of the host robot. All adapter-key positions must be considered precision positions and must be programmed as such.)

Step 6. Reconnect the air lines to the actuator.

Step 7. Under pneumatic control, open and close the Foreman Hand fingers over the adapter-key prongs several times. If the prongs are not inserted freely, repeat steps 2 through 5.

Step 8. Attaching and releasing the adapter keys is accomplished via a pneumatic locking mechanism inside each finger. Requiring 65–85 psi lubricated or nonlubricated air and controlled by the host robot computer's I/O, the locking mechanism must be actuated when the fingers are in the proper position. Figures 3a, 3b, and 3c show adapter-key acquisition for one style of nesting. To release the adapter key, reverse the function processes.

SIX DISTINCT PICKUP MODES

Foreman Hands have the flexibility of acquiring tools or work pieces in several ways.

Mode 1, Mode 2 Finger Pickup. Foreman Hand actuators were specifically designed to operate the fingers in the expansion and contraction modes. Rubber contact pads on the inner and outer surfaces of the fingers ensure grasp integrity for o.d. and i.d. type pickups. (See Figure 3.)

Mode 3, Mode 4. Adapter keys can be attached to the inner and outer surfaces of

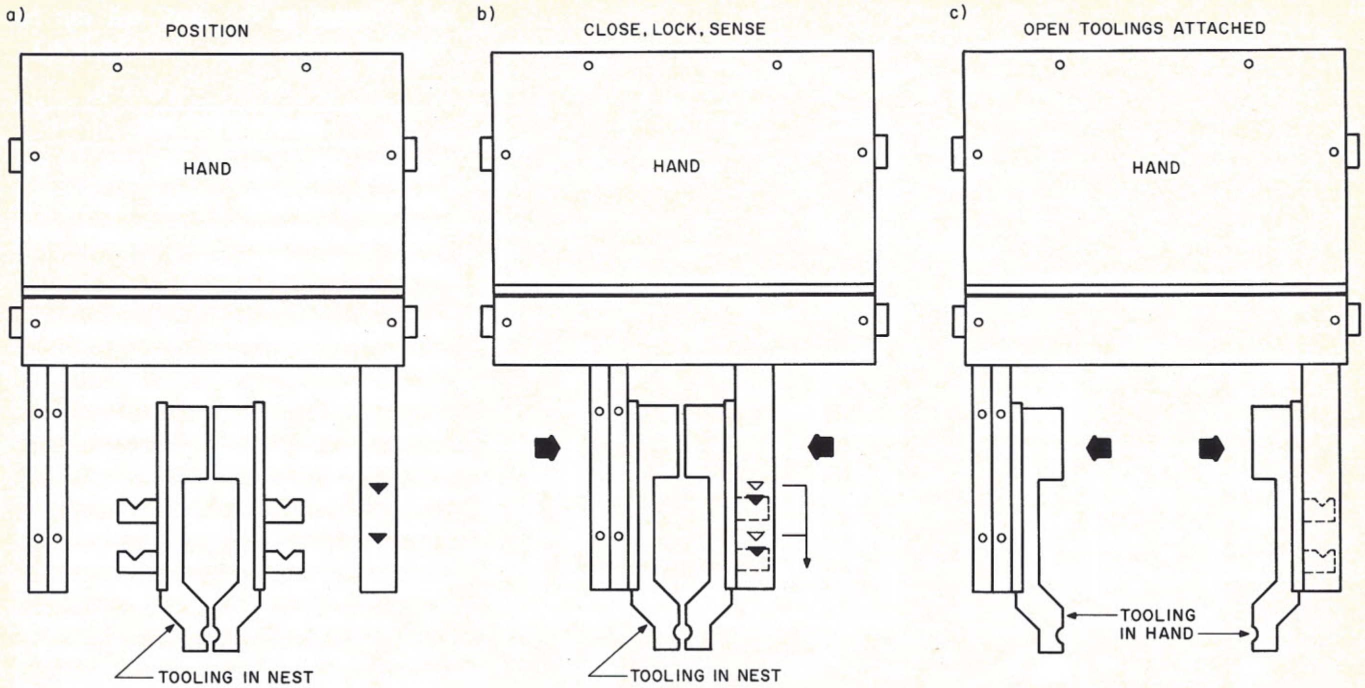


Figure 3. Mating a set of tooling to the Foreman Hand is a three-step process. The unused tooling is kept in a nesting location, approached by the open fingers of the hand (a). The hand is then closed over the tooling, mating adapter keys to the unlocked receptacles (b). The receptacles are then locked, and the hand plus tooling can be removed from the nest and opened (c).

the fingers, thus allowing them to sweep freely open and closed with the motion of the fingers. (See Figure 5.) The hand can thus acquire custom tooling for a variety of operations—multipart, small parts, odd-shaped parts, large parts, and others.

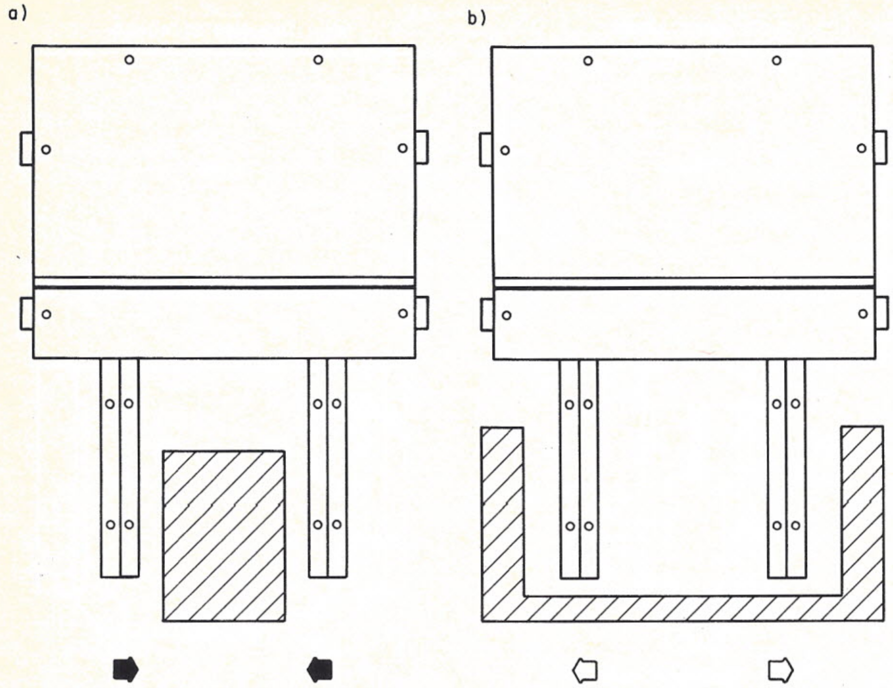


Figure 4. Expansion (a) and contraction (b) modes of gripping with the Foreman Hand. In these illustrations, gripping is done without adapter plates, with the jaws unconstrained.

Mode 5, Mode 6 Adapter-Key Fixed Pickup. Adapter keys can be mounted to a variety of off-the-shelf tools, such as solder mask, epoxy, drills, component insertion, lasers, and water knives. Also, jigging trays and other objects that need to be relocated in the work cell can be handled in this matter. (See Figure 6.)

SENSORS/FEATURES

Sensors, which play a big part in the automatic assembly process, enable the hands to intelligently perform their work duties in the robot cell.

Noncontact Sensing. An optoelectronic infrared emitter detector pair centrally located one-tenth of an inch from the fingertips can detect the presence of an opaque object entering the finger grasping area. Since robots commonly acquire parts from conveyors and part feeders, the signal from the beam can be monitored to sense the presence of a work piece before the end effector goes into its grasping mode. Through programming, missing parts can be detected, and a work cell can respond in several ways—cell shutdown, alarms activated, or conveyors indexed to next part position, for example. A variety of optics can also be mounted to adapter keys to reroute the beam to a desired position with each adapter-key set acquisition. Fiber optics, rhomboid prisms, and other

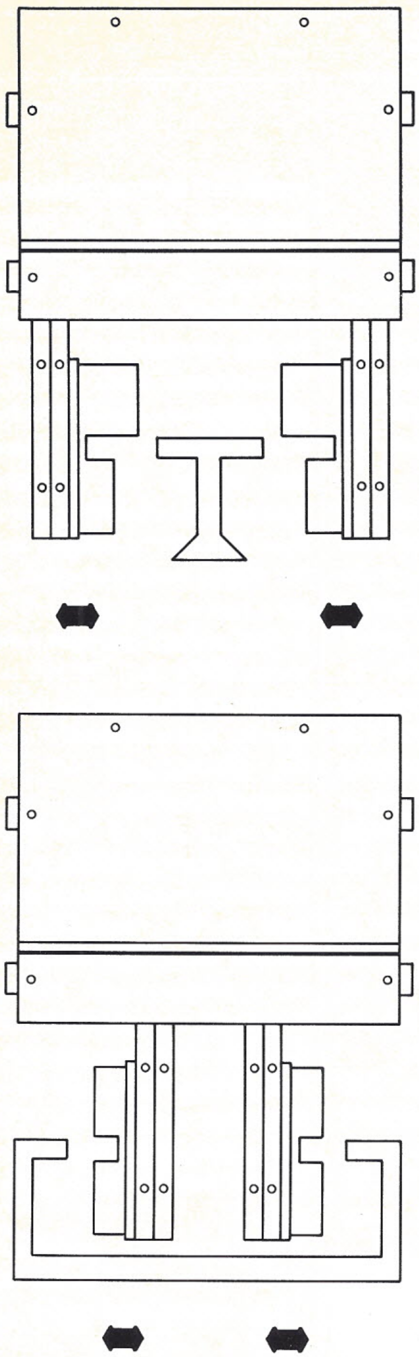


Figure 5. Free pickup with adapters. In this set of examples, expansion- or contraction-mode gripping is done with special-purpose tooling mounted on adapter plates. The gripper opening—with tooling—is free and unconstrained.

methods of work piece detection have been successfully tested.

Tool Lock Sensing. Optic sensors in each finger have been added for verifying acquisition and proper positioning of the adapter keys. Properly acquired adapter keys will produce a signal to the host robot computer to permit the program to continue.

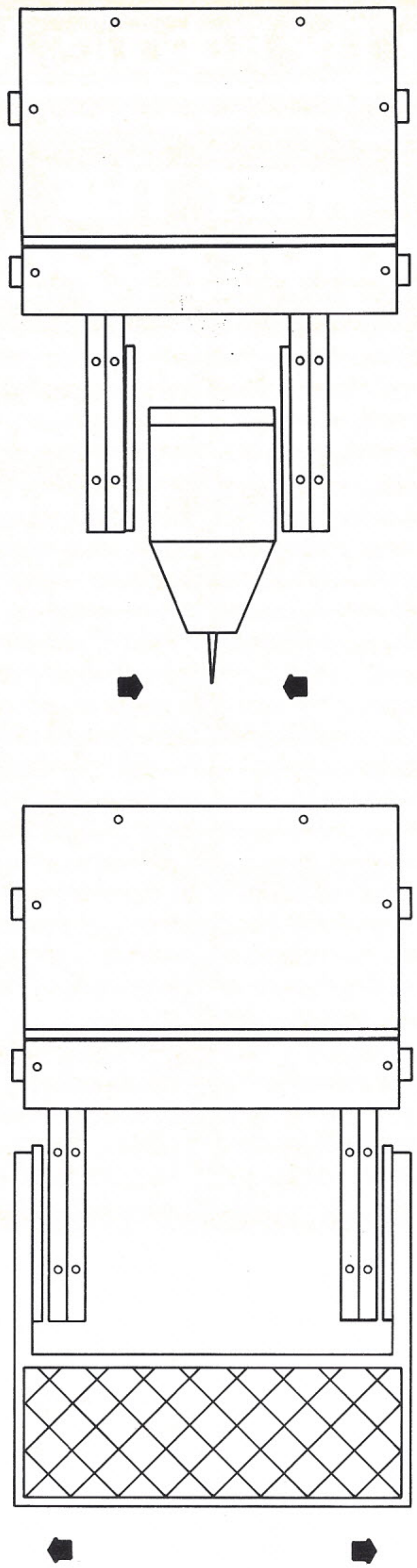


Figure 6. Fixed pickup with adapters. In this pair of examples, the motion of the Foreman Hand gripper fingers is used to mount tools, fixed-position jigs, part trays, etc., while the adapter keys remain in a fixed position.

Programmable Finger Positions/Gauging. Often in the assembly process there is a need for the end effector fingers to come to a fixed position, read the predetermined position, verify it, or report the position to the host controller for processing. To achieve this, a capacitive linear position sensor using pulse-width modulation was built and installed in the upper frame of the hands. Using a small microprocessor, a pneumatic servo, and an RS-232 interface, 256 finger positions (approximately every 15 thousandths of an inch) can be commanded from the host robot's computer program. The hand controller takes the entered position as an 8-bit integer number from 0 to 255 and sets the fingers of the hand accordingly with an accuracy of 0.004 in. The hand controller also can send back the current hand position to the host controller for verification. Gauging is possible using this technique.

For example, the hand can be positioned over a conveyor having a variety of part sizes. From a full open position, the hand can be asked to move to full close, grasping the part in the interim. Once in the grasp, the hand controller can send the current position to the host controller, which can dictate the next robot process.

ADVANTAGES OF FLEXIBLE END EFFECTOR TOOLING

By using an interchangeable end effector tooling technique, a single work cell can be set up to accomplish multiple tasks. The technique is similar to proven technology of NC milling and drilling machinery with interchangeable bits. Here, however, we have a nest of multiple specialized end effector tools that can be changed under programmable control. During an assembly stage, the gripper can attach to a series of active and passive tools selected from a nest. By multiplying the number of tasks an individual work cell can perform, the interchanged end effector technique enhances productivity.

Mathew L. Monforte is president of Monforte Robotics, Inc. An inventor and designer, he worked in the aerospace and robotics industry prior to founding his own company.

Edited by Stephanie vL Henkel

MEET THE MOTOR MOUTH

An artificial mouth designed to speed up the testing process of dental materials is being developed at the University of Minnesota's School of Dentistry. This robotic oral environment mimics the complexities of chewing (a multidirectional motion) and even squirts artificial saliva. The mouth, outfitted with real teeth, can simulate in just eight hours three to six months' normal human chewing.

Dr. William Douglas, working under a grant from the National Institute of Dental Research, teamed up with two colleagues (one of whom has a Ph.D. in physics in addition to his D.D.S.) to create ART, for Artificial Resynthesis Technology. A fourth member of the team is MTS Corporation, a Minnesota firm specializing in engineering and hydraulics equipment.

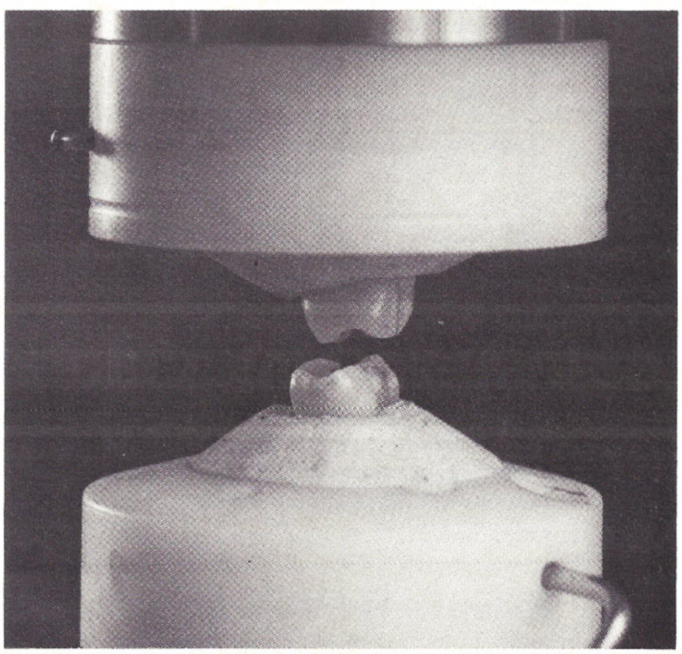
ART consists of two vertically opposed "jaws," in which four freshly-extracted teeth are fixed, two above and two below. (Some projects will involve the whole arch.) To duplicate the function of the gums, the teeth are mounted in an acrylic base that acts as a shock absorber and allows the teeth to dislocate slightly and then reposition themselves as they do in a real mouth. Four jets provide a liquid lubricant that performs the function of human saliva. ART bites four times per second, about the rate of a fast chew. Because ART can bite 24 hours a day, wear on natural enamel and on restoration materials requires a much shorter testing time than is needed in a human mouth.

Douglas's research focused on two problem areas: perfecting the natural motions of the mouth, and recreating the temperature fluctuations experienced in a mouth that, say, has a cup of coffee with a dish of ice cream. The latter problem was solved by a process based on thermal cycling, the body's attempt to maintain itself at a constant 98.6 degrees. Anything of an extreme temperature taken into the mouth usually makes a quick trip past the teeth, with no penetrating effect on the enamel. The system devised for ART shoots first a small amount of hot water followed immediately by a spray of cold to simulate rapid temperature changes.

The masticatory, or chewing, cycle was more difficult to emulate. To control both force and motion simultaneously, a servohydraulic system with closed-loop control was used. There are three phases in mastication: preparatory, during which the mandible, or jawbone, is positioned; crushing, during which the molars compress the bolus, or bite of food; and gliding (or grinding), during which the bolus is ground between the molars.

The first two phases are carried out under muscular control. Gliding is achieved under displacement or stroke control defined by tooth anatomy. When the teeth come into contact during grinding, they slide along each other until the peaks and valleys of opposing teeth align. The sliding motion describes an arc with a center of rotation just in front of the ear lobe opposite the chewing side. The point of rotation is not fixed, but moves in an arc with a very large radius (8 to 10 cm) in comparison to the described arc (1 to 2 mm).

The three-dimensional gliding movement can be described by motion in two planes, the horizontal and the frontal. Horizontal movement is approximated by straight-line motion, while that of the frontal plane is defined by occlusal anatomy, the way the teeth come together while chewing. In the servohydraulic system, the anatomic loads and displacements are supplied by hydraulic actuators under closed loop control. The haversine load applied to the teeth is provided by a vertical actuator and the sliding motion of grinding by a horizontal actuator. The vertical actuator also opens and closes ART's jaws. The two actuators are synchronized to ensure the load is supplied during the grinding and not the preparatory phase.



Loading during the glide phase is accomplished by inputting the desired electronic waveform into the control of the vertical actuator. The waveform can be programmed to provide a constant contact load during the glide phase, or a haversine contact load that closely simulates anatomical loading. The glide phase contact load is controllable from 1–1000 lb. (4.45–4450 N).

The horizontal actuator is under stroke control at all times, moving back and forth along a straight line approximating the arc of the grinding phase. The vertical actuator undergoes two mode switches per cycle. Its control mode is switched from stroke to load control at the beginning of a grinding phase, and back to stroke control at the end of the phase. The arc of the sliding motion can be approximated by a straight line with very little error.

An additional discovery arising from Douglas's research has been a means of measuring tooth wear in very small increments. An experienced den-

tal clinician can detect a change in a tooth or restoration at about 40 to 50 microns, but the computer can see 4- to 5-micron changes. Early detection of minor changes in a natural tooth, or in a dental product, can help prevent a more serious problem from developing. To determine the amount of material worn off the surface of a tooth or restoration, the tooth surface is profiled before, during, and after testing.

The MTS test system uses a precise displacement stylus and a programmable data acquisition system to generate a tooth profile. The horizontal actuator draws the stylus across the tooth, tracing its contour. The stylus also controls the movement of the vertical actuator. Displacement data from the horizontal and vertical actuators' linear variable displacement transducers is gathered. The data provides a contour line of the tooth in the plane of stylus motion. The stylus is then moved over to trace another contour line parallel to the first. This is repeated until a three-dimensional profile of the chewing surface is obtained. Subsequent profiles of before and after testing are overlapped and matched by aligning areas of the tooth not subjected to wear. The volume between these profiles is then calculated and attributed to wear. ■

FIRST IEEE ROBOTICS CHAPTER

The Boston Section of the Institute of Electrical and Electronics Engineers (IEEE) has formed a Robotics Chapter, the first such chapter in the country sponsored by the IEEE. The chapter will be interdisciplinary, and joint meetings with other societies both outside and inside the IEEE are anticipated.

The Robotics Chapter's areas of interest will include: robotic kinematics and dynamics; smart sensors, sensor systems, and feedback control; CAD/CAM/CAE; control languages; artificial intelligence; process design and control; hierarchical computer control; and drive systems and controllers.

The inaugural meeting, planned for 17 April, will feature Dr. Tomas Lozano-Perez of the Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, who will speak on "Object Recognition and Localization Using Models."

Anyone interested in joining the new robotics chapter or obtaining more information about it may write Dr. Robert E. Parkin, Dept. of Electrical Engineering, Lowell State University, 1 University Ave., Lowell, MA 01854, or telephone him at (617) 452-5000, ext. 2295. ■

CORPORATE NEWS

► Several personnel changes have been announced by **RB Robot Corp.** of Golden, CO. **Joseph H. Bosworth** has resigned as chairman of the board and president, and has been replaced by **Earle H. Stevenson.** Bosworth will remain a director and will represent the company as an independent marketing agent. **William A. Frederick**, a director of the company since its inception, has been replaced by **John J. Collins**, and **Joseph M. Collins** has been elected vice president. The board of directors has also announced that on 1 February 1985 John J. Collins acquired from Bosworth nine million shares of the Golden, CO, company's stock.

► The first **National Medal of Technology** to be conferred upon a company has gone to **AT&T Bell Laboratories**. The award, created by a 1980 act of congress, recognizes individuals and companies that have "advanced United States competitiveness in world markets, created new jobs, and made technological contributions to industries and people everywhere." AT&T Bell received the honor from President Reagan for "contributions over decades to modern communication systems." Individuals receiving medals were: Joseph F. Sutter, Boeing Commercial Airplane Co.; Bob O. Evans, Frederick P. Brooks Jr., and Erich Block, formerly of IBM; Allen E. Puckett and Harold Rosen, Hughes Aircraft Co; Marvin M. Johnson, Phillips Petroleum; John T. Parsons and Frank L. Stulen, John T. Parsons Co.; Steven P. Jobs and Stephen G. Wozniak, Apple Computer; and Ralph Landau, formerly of Halcon S.D. Group, Inc. ■

MARKET RESEARCH

Medium-volume production of military robots will have begun by 1988, according to research conducted by **International Resource Development, Inc.** The company has released a 252-page report forecasting an annual production of military and paramilitary robots in excess of $1/2 billion by 1994, and an additional $1 billion will be spent on research and development of military robots and artificial intelligence.

The first robots will move on tracks or wheels, the study says, but the future will bring devices on four or even two legs. The report describes self-navigational abilities as critically important and cites the "profuse" number of contracts awarded to universities and think tanks for research on artificial intelligence for robot navigation.

One particularly important application of the military robot is ammunition handling. The Battlefield Robotic Ammunition Service System (BRASS) uses robotic "snaggers" and "crunchers." The snagger finds and grabs a pallet of ammunition and moves it into position beside a gun. The cruncher inserts the fuses and prepares the round for firing. Some systems also use a "stasher" that readies the ammunition for snagging.

The use of robots instead of humans is expected to be especially significant in extreme climatic conditions and in situations in which soldiers are likely to suffer from fatigue or impaired efficiency. Still, the report predicts that the officers might not be entirely enthusiastic in that more robots will mean fewer humans in a command with a resultant decline in an officer's career opportunities. Also, human supervisors in the battlefield will have to be prepared for equipment malfunctions that could lead to disaster. As IRD research staff member Jocelyn Taylor points out, "Getting sideswiped by a 'friendly' robot isn't any more fun than being caught in 'friendly' fire."

A market study conducted by **General Electric** reflects a 26 percent rise last year in robot sales, but no corresponding rise in profits. Total 1984 sales are expected to be about $311 million, a figure spread among 300 firms worldwide offering robotic systems (up from 50 in 1979).

Wall Street analysts had predicted a 50 percent growth rate for the robotics industry last year. G.E.'s Vern Estes, manager of product planning and market development for the Robotics and Vision Systems Dept., said the perceived lackluster performance of the industry had seriously dampened the enthusiasm of venture capitalists.

Estes said also that customers want turnkey systems installed and completely debugged by the robot vendor, reflecting the fact that most firms have found robotic applications more difficult and expensive than they had originally estimated. Said Estes, "This industry will be a success when both vendor and client realize that successful implementations, like good marriages, require an equal effort from both sides for a 100 percent successful system."

DM Data, Inc. has released a report predicting a $5 billion United States market for artificial intelligence by 1990. The figure is based on sales of AI equipment and software in the areas of expert systems, voice recognition, visual recognition, and natural language interface.

The report, however, indicates concern throughout the industry that AI technologies might have been oversold during 1984. The consensus is that the state of the art has been misrepresented in that even though there have been new breakthroughs in machine capabilities, AI still does not impart any semblance of intelligence to computers.

DM Data's annual report reviewed the entire AI industry from both a business and technological perspective, as well as government involvement in AI from defense contracts to research funding. ■

ROVER'S A ROBOT

Looking for a cat or dog that never eats, drinks, or misuses your carpet? One you can turn off when you're tired of playing? Well, it could be that the Petster is the furry friend for you.

It seems Atari and Androbot founder, Nolan Bushnell, is now CEO of Axlon, and Axlon is responsible for the Petster. A recent article in *ElectronicsWeek* brought these creatures to our attention, and we gather they are closely related to the little dogoid on the former TV show, "Lost In Space." With one significant difference: They're not always happy.

For the Petsters are said to have *temperaments*. They are mobile and sensitive to light and sound. And they have on-board computers with 4-bit custom microprocessors with 4 Kbytes of ROM and some RAM, allowing them to act merry or mopish, peppy or pooped.

Bushnell predicts that the Petster "will replace biological animals as pets and companions." Well, at least if your companion's having a bad day you'll know it's nothing *you* did. ■

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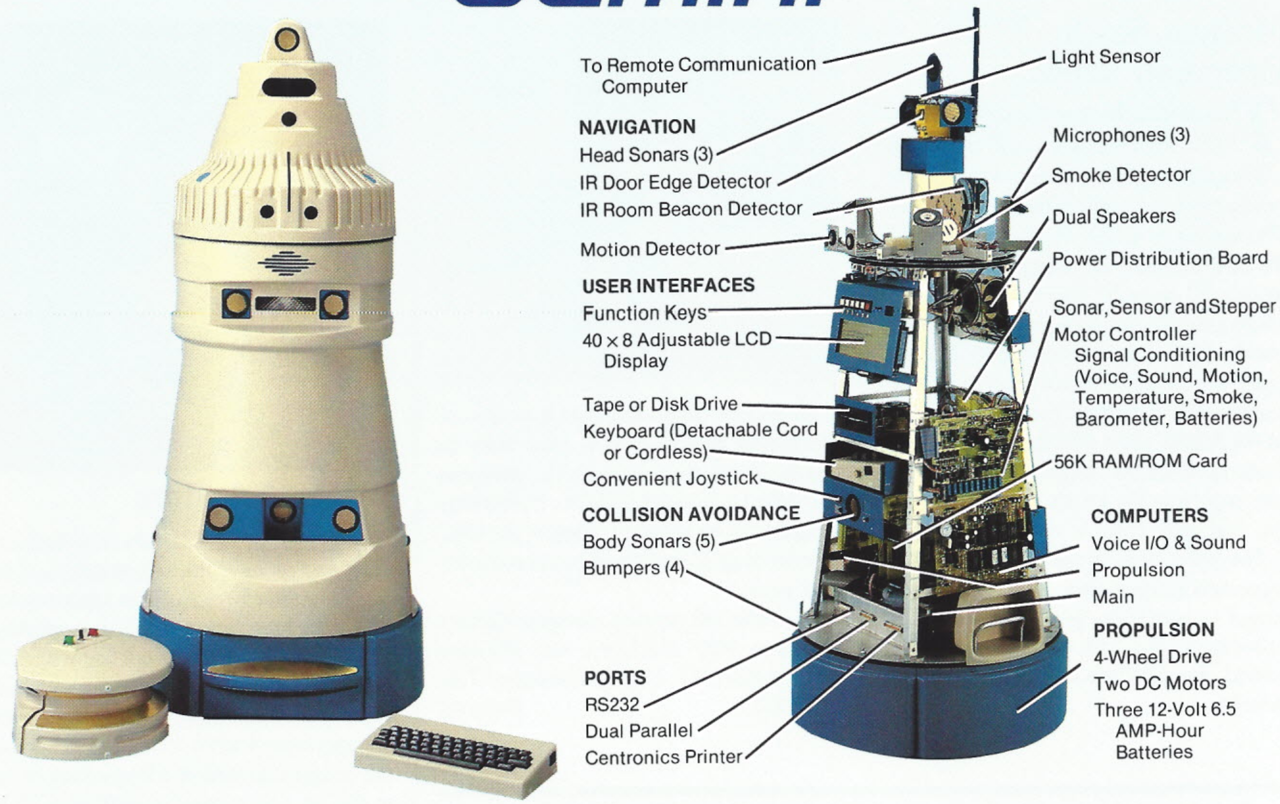

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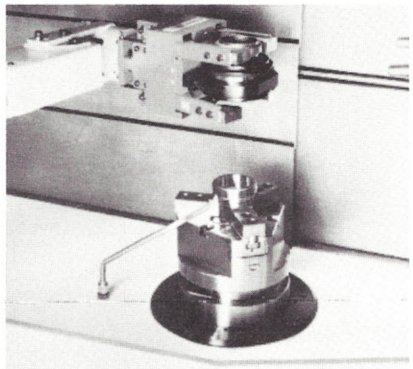
New Products

Continued from page 25

Medium Batch Operation Robot

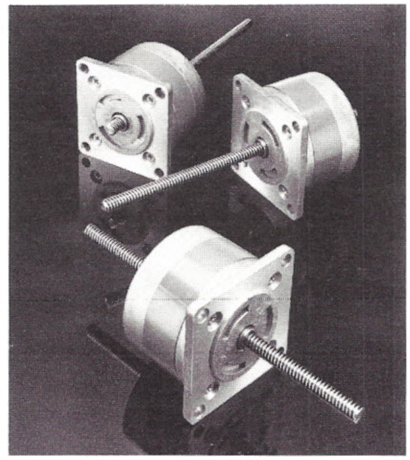
The MTC-3 Turning Center offered by MHP Machines has a GMF robot with a 20-position carousel designed to improve productivity for medium batch operations. The robot can handle workpieces up to 11 lbs. and permits part-changing in approximately 20 seconds. This is accomplished via an arm with three-axis movement: along the machine's Z axis to move parts into and out of the chucks (robot X axis), across the machine's X axis from carousel to chuck (robot A axis), and a 270-degree wrist movement in 90-degree increments to remove one part from the chuck index and insert the next part (robot α index).

The robot has its own control and is separately programmed; the programs are stored in battery backed-up RAM and recalled as needed. Arm movements are controlled by mechanical stops and limit switches.



Each of the 20 positions on the carousel can handle an 8 in. by 6 in. plate made to suit the part to be machined. The parts can be stacked to a height of 11.5 in. Postprocess ganging can be linked to offsets in the CNC control to good parts and compensate for tool wear.

For more information, contact: Michael Mortimer, MHP Machines, Inc., PO Box 143, Buffalo, NY 14225, telephone (716) 668-0221. Circle 45



Linear Actuators

Eastern Air Devices has introduced a new series of linear actuators said to achieve greater force and finer linear resolution than have heretofore been available. The bidirectional devices contain a size 32 permanent magnet stepping motor with 200 steps per revolution. They come with voltages from 4 to 24 VDC. The actuators are designed to achieve a linear force of up to 657 oz. and a linear travel from 1.25 X 10^{-3} in. to 0.3125 X 10^{-3} in. per 1.8 degree step.

The internal rotating nut is made of SAE 660 bearing bronze, and the actuating shaft is a ¼ X 16 ACME rolled thread of CRS. Models are available with leads of $\frac{1}{16}$, ⅛, or ¼ in. Custom models can be provided also.

For more information, contact: Fred Phillips, Eastern Air Devices, 1 Progress Dr., Dover, NH 03820, telephone (603) 742-3330. Circle 47

Robot-Selection Software Package

Robot Calc is offering a complete robotics directory, analysis, terminology, and justification guide computer program designed to assist robotics engineers and researchers. The Robot-Calc 1 package consists of two floppy disks and a leatherlike folder for storage.

The program can be used on IBM or IBM-compatible computers. A database directory lists hundreds of industrial robots with standardized specifications and over 100 domestic and foreign manufacturers and suppliers marketing in the United States.

For more information, contact: Robot Calc, Inc., PO Box 930, South Bend, IN 46624, telephone (219) 282-8100. Circle 46

Servocontrolled Electric Industrial Robots

Prab Robots is offering four models of electric drive, servocontrolled industrial robots: the G-24, G-26, G-34, and G-36. All four feature a patented, five-link kinematic design that makes them highly versatile and extremely accurate, the company says.

The DC electric-drive robots can simultaneously perform eight axes of motion including items such as transverse base and/or positioning table. All axes have permanent magnetic brakes. Models 24 and 34 have four axes as standard, while models 26 and 36 have six. The four-axis units are equipped with a wrist linkage that keeps the last axis faceplate in a normal vertical or horizontal plane throughout the work envelope and all programmed moves. Payload capacity ranges up to 145 lbs. (65 kg) at maximum speed. An enhanced software package permits heavier payloads.

When interfaced with the G-Series controller (Model 800), the robots offer point-to-point, multipoint, and continuous-path capabilities including linear, circular, and spline interpolation. The robots use digital encoders for "absolute" feedback of servocommands. Applications include parts handling, deburring, grinding, water-jet cutting, light and heavy spot welding, palletizing, adhesive dispensing, and assembly.

For more information, contact: Prab Robots, Inc., 6007 Sprinkle Rd., PO Box 2121, Kalamazoo, MI 49003, telephone (616) 329-0835.

Circle 48